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Developing pre-service teachers' computational thinking: a systematic literature review

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Abstract
Recently, computational thinking (CT) has gained importance in education systems worldwide, specifically the CT training of pre-service teachers. This study conducted a systematic literature analysis (2011–2021) of 38 works on pre-service teachers' CT based on Web of Science, Science Direct, and Google Scholar databases. The results were as follows: (1) Six training methods were found, (2) CT training effectively improved pre-service teachers' CT, (3) A positive relationship was found between pre-service teachers' CT ability and the five factors affecting the ability, (4) A mode of training to improve CT ability of pre-service teachers and the relationship between CT ability and teaching methods were considered. This study suggested ideas for designing training modules of CT ability and a reference for realizing the best training effect. Finally, future research trends and a general model of training were presented as references for researchers, instructors, and policy makers to promote the CT of pre-service teachers.

Keywords Computational thinking · Pre-service teacher · Teacher training · K-12 · Training methods

Introduction

Recently, research on computational thinking (CT) has become the focus of international curriculum education reform in K-12 schools. Several countries, such as the US, China, Australia and Canada, have introduced policies to include CT in K-12 education, while increasing financial spending to support CT research (Grover & Pea, 2013; Wang et al., 2019). However, most research on CT focuses on K-12 students, with little research on CT of K-12 teachers, especially pre-service teachers. To improve students' CT ability, the content should be integrated into K-12 curricula to enable pre-service teachers to develop CT skills for future teaching requirements (Yadav et al., 2014). Additionally, it is important for future teachers to equip themselves with such skills (Esteve-Mon et al., 2020).

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Consequently, few countries have started emphasizing, the development of pre-service teachers' CT and implementing measures to help them. In 2011, the US National Science Foundation proposed that 10,000 teachers in 10,000 high schools should be able to teach high-quality computer science by 2015 (Computing Education Blog, 2011). Since September 2017, the Institute of Education in the Northwest of Switzerland has initiated a compulsory computer science education course for pre-service teachers to improve their CT and meet future teaching needs (Lamprou & Repenning, 2018). Therefore, given the increasing attention toward pre-service teachers' CT, there is a need to develop a series of CT training to improve these teachers' CT ability and to teach CT across content areas (Cutumisu et al., 2021).

Previous research entailed more of an exploratory investigation into the CT of pre-service teachers (Cutumisu et al., 2021; Esteve-Mon et al., 2019). However, there has been a lack of systematic studies related to pre-service teachers' participation in CT learning and teaching (Yadav et al., 2017). Thus, this study conducts a systematic literature review to explore the current research status of pre-service teachers' CT, the effective methods to improve pre-service teachers' computational thinking and the relevant factors affecting CT ability. These efforts help recommend suitable CT training model for future teachers.

Definition of CT for pre-service teachers

More teachers currently require certain CT abilities that they can integrate into future classroom practice (Sadik et al., 2017). As a universal ability in the twenty-first century, the relevant definition of CT is also universal (Rajecki, 1990). CT originated from Logo teaching by Seymour Papert (Papert, 1996). Logo is a programming language designed to teach heuristics and formal methods (Feurzeig & Lukas, 1972). Papert (1996) proposed the term "CT" in a paper on mathematics education, in which he discussed a computer as a tool to solve problems and how it can help analyse and solve problems. The concept of CT was defined and advocated by Wing (2006). Wing emphasised that unlike computer programming, CT included a way of thinking and solving problems. This view added an abstract quality to CT. Both Wing and Papert clearly showed that CT was not just blind use of computers, but a method of solving problems. Brennan and Resnick (2012) further developed the definition of CT as involving three key dimensions: computing concepts, computing practices, and computational perspective. These dimensions provide a theoretical framework for CT research.

However, the definition of CT was too broad, and previous research did not agree on the common elements or components of CT (Barr & Stephenson, 2011). For example, Angeli et al. (2016) listed the inherent elements of computational thinking, such as abstraction, generalization, algorithmic thinking and so on. Moreover, attitude elements such as confidence, perseverance, and collaboration were also found to be associated with CT (Barr et al., 2011). In response, Voogt et al. (2015) indicated that instead of defining CT, similarities and relationships should be sought in discussions about CT. Table 1 provides the definitions of CT proposed in previous studies.

Therefore, in this study, the conceptual boundary of 'CT' is defined according to existing definitions, which we used to conduct relevant literature search. The definitions of CT in previous studies are summarised to screen relevant research results: (1) CT is a problem-solving skill that helps use computers and other tools to solve problems (Barr et al., 2011). (2) CT includes problem decomposition, algorithmic thinking, data collection, analysis

Table 1 Definition of computational thinking

Article	Definition
Papert (1996)	CT is an important thinking ability for the use of computer to analyse and solve problems
Wing (2006)	Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science
Barr and Conery (2011)	The basic dimensions of computational thinking include: confidence in dealing with complexity; persistence in working with difficult problems; tolerance for ambiguity; the ability to deal with open-ended problems; the ability to communicate and work with others to achieve a common goal or solution
Brennan and Resnick (2012)	Computational thinking involves three key dimensions: computational concepts (the concepts designers employ as they program), computational practices (the practices designers develop as they program), and computational perspectives (the perspectives designers form about the world around them and about themselves)
Angeli et al. (2016)	Computational thinking is a thought process that utilizes the elements of abstraction (removing characteristics or attributes from an object or an entity in order to reduce it to a set of fundamental characteristics), generalization (developing solutions using generic terms), decomposition (breaking down complex problems into more tractable parts), algorithmic thinking (using a precise sequence of steps or instructions to solve a problem), and debugging (detection and correction of errors)

and presentation, decomposition, debugging, creative thinking, critical thinking, and confidence in dealing with complex problems (Angeli et al., 2016; CSTA & ISTE, 2011; ISTE, 2015).

Intervention factors of pre-service teachers' CT

Currently, more effort needs to be made for incorporating CT into teacher education. Studies have shown that when information about CT is provided to future teachers, they become more positive about computer science and are tend to incorporate CT into future instruction (Yadav et al., 2011). The relevant factors affecting pre-service teachers' CT provided in different studies and their influence on teachers are explored, as given below.

Training methods

Yadav et al. (2017) found training methods and tools have a significant impact on the CT ability of future teachers. To improve their CT, the improvement and diversification of relevant methods have been focused upon. Past reviews and empirical studies have not followed a uniform standard for the classification of CT training methods in different studies.

Therefore, this study classifies pre-service teachers' CT training methods according to the content of the included literature, various factors, and a series of standards such as the classification of CT learning strategies and learning tools applied in previous studies. In a literature review on CT, Hsu et al. (2018) proposed a specific classification of CT learning strategies and programming learning tools (e.g. project-based learning, involvement-based learning, game-based learning, Scratch programming language, C++programming

language, etc.). The common and effective design-based learning method among them is the development of CT modules (Shanmugam et al., 2019). In addition, in a systematic review of CT methods in higher education, the tools and methods used in teaching and learning CT are summarised and classified into courses, seminars, exploratory research, game-based learning, programming software-based learning, educational robots (ER), etc. (Agbo et al., 2019). A review by Papadakis (2021) considered programming apps as a way to cultivate CT in young children. Based on the above research, we can organise the training methods involved in the included literature in combination with the specific situation. Therefore, the training methods to improve the CT level of pre-service teachers are as follows:

Analysing relevant research revealed that a range of training methods were to improve pre-service teachers' CT: CT courses, programming applications, ER training programs, CT module, CT projects, CT seminars. Table 2 provides details of methods to improve CT training for pre-service teachers.

Thus, the development and application of training methods in previous studies were diverse. This study summarised the main training methods for an in-depth analysis.

Influence factors

Previous studies showed that the CT of pre-service teachers was influenced by several factors. For example, a CT module embedded in an educational technology course had the potential of improving pre-service teachers' CT understanding and attitudes (Zha et al., 2020). Additionally, pre-service teachers showed a more positive attitude toward the learning and application of CT after training, and they were more willing to use CT in future teaching (Cutumisu & Guo, 2019; Yadav et al., 2011). A literature analysis showed that pre-service teachers' self-efficacy, self-confidence, interest, willingness and attitude influenced their training. Self-efficacy refers to people's confidence to use their skills for the completion of a job behavior (Bandura and Wessels 1994). The study has shown that teachers' self-efficacy will have an important impact on teachers' teaching and learning (Tschannen-Moran & Hoy, 2007). In addition, pre-service teachers' confidence and interest are vital to improve their CT. Confidence and interest will facilitate teachers' acceptance of learning of CT as well as understanding of relevant knowledge. Moreover, this will help them better use robots to teach programming and CT in school classrooms (Piedade, 2021). Teachers' willingness is also crucial to improve their CT ability. Only when teachers are willing to learn relevant CT knowledge can their understanding and application of CT be further improved (Alqahtani et al., 2022). Furthermore, research has shown that people's attitude is composed of emotion, behavior, and cognition. Additionally, people's emotions can predict the results of their behaviours (Rajecki, 1990). Therefore, this study included pre-service teachers' emotional factors in the intervening factors, while offering relevant suggestions.

CT skills

As CT becomes a thematic content in the field of education, more and more researchers begin to explore a series of skills contained in CT. For example, some researchers believe that CT includes skills related to problem solving, problem understanding, problem definition, abstraction, logical thinking, debugging and pattern recognition (Barr & Stephenson, 2011; Ngan & Law, 2015; Wing, 2006). In order to better explore

Table 2 Methods to improve pre-service teachers' CT

Methods	Definition	Implication
CT courses	It is a systematic and complete course designed to teach CT and programming to pre-service teacher's (Umutlu, 2021)	The CT course is able to help future teachers learn and understand CT knowledge and skills, develop their own CT, and analyze how CT should be integrated in their disciplines (Mouza et al., 2017; Papadakis et al., 2019)
Programming applications	Educational programming application is a tool that is applied to the learning and teaching of pre-service teachers' computational thinking and creates an educational environment for teachers to learn the basic knowledge of programming (Kalogiannakis & Papadakis, 2017)	Programming applications enable to introduce pre-service teachers to programming to create a space for innovative thinking and a platform for developing CT for pre-service teachers (Papadakis et al., 2019; Pala &Mıhcı Türker, 2021; Saez-Lopez et al., 2020)
Educational Robot (ER) Training programs	Educational robotics is a powerful approach to teaching and learning that inspires pre-service teachers to construct and program robots using a specific programming language to solve a problem (Piedade et al., 2020)	Enhancing pre-service teachers' programming abilities through ER programs is conducive to the development of future teachers' CT (Jaipal-jamani & Angeli, 2017)
CT module	CT module is a part of the curriculum content needed to improve the computational thinking of pre-service teachers, which is generally embedded in the compulsory courses of education majors (Yadav et al., 2014)	Embedding CT module in the professional courses of pre-service teachers can help them better integrate CT with professional knowledge, especially for teachers who are not in computer science education (Bean et al., 2015; Yadav et al., 2014)
CT projects	CT project is a long-term task of organizing manpower, materials and other resources by using various methods. According to relevant planning arrangements, it is a systematic work to improve pre-service teachers' computational thinking (Minguell et al., 2017)	CT projects that include beneficial teaching activities can improve pre-service teachers' CT ability (Minguell et al., 2017)
CT seminars	The CT seminar is a workshop that has helped teachers gain some understanding of CT and computer programming in a short period of time (Perez et al., 2014)	In addition, CT workshops enable pre-service teachers to provide relevant resources, activities and course materials (Perez et al., 2014)

the influence of various factors on the CT ability of pre-service teachers, this study reviewed the CT skills mentioned in the previous research literature and combined with 38 included studies to summarise 9 kinds of CT skills for analysis. They are critical thinking, creative thinking, abstraction, debugging, decomposition, problem solved, algorithmic thinking, programming or coding skills and concept understanding. Table 3 provides a detailed definition of CT skills.

Research purposes

Although some studies have provided relevant schemes to promote teachers' CT, there has been a lack of systematic integration of effective training methods. This study aimed to conduct a systematic literature review and attempted to classify and integrate the CT training for pre-service teachers. Second, factors in the training process were analysed to explore whether these factors have an impact on the improvement of pre-service teachers' CT. This paper addressed the following research questions:

RQ1 What research methods were used in previous studies?
RQ2 In previous studies, what methods were used to promote pre-service teachers' CT?
RQ3 What were the main factors interacting with pre-service teachers' CT in previous studies?
RQ4 How does one establish the development model of pre-service teachers' CT with existing training methods?

Table 3 The classification of pre-service teachers' CT skills

CT skills	Definition
Abstraction	Identifying and extracting relevant information to define main ideas (Barr & Stephenson, 2011; Grover & Pea, 2013; Wing, 2006)
Critical thinking	The use of cognitive skills or strategies that increase the probability of a desirable outcome (Halpern, 1996 p. 5)
Decomposition	Breaking down data, processes, or problems into smaller, manageable parts (Atmatzidou & Demetriadis, 2016)
Programming or coding skills	The knowledge and skills gained through learning computer programming or coding could develops capabilities to think conceptually and problem solve at multiple levels of abstraction (Popat & Starkey, 2019; Wing, 2006)
Debugging	Find your own mistakes and fix them (Atmatzidou & Demetriadis, 2016; Berland & Lee, 2012; Yadav et al., 2014)
Problem solved	The final step of logical thinking (Ngan & Law, 2015)
CT concept	Pre-service teachers' understanding of CT evolved from how Calculations are made by computers to how complex problems can be solved through step-by-step plans (Umutlu, 2021)
Creative thinking	creative thinking' reveals the kind of thinking that leads to new insights, novel approaches, fresh perspectives, whole new ways of understanding and conceiving of things (Eragamreddy, 2013)
Algorithms	Creating an ordered series of instructions for solving similar problems or for performing a task (Barr & Stephenson, 2011; Grover & Pea, 2013)

Methods

This research conducted a systematic literature review, and the relevant literature was analysed and integrated through the CT training of pre-service teachers. A systematic review of the literature is considered as the most rigorous review because a high-level summary of the available evidence is presented (Gupta et al., 2018). Moreover, it is designed to provide a fair evaluation of a research topic using reliable, rigorous, and auditable methods that focus on answering a precise question (Kitchenham, 2004). A systematic review involves several discrete activities. We followed a defined process for conducting systematic reviews based on Kitchenham (2004), covering the following stages and activities: planning, conducting and reporting the review. The stages associated with planning the review are: identification of the need for a review and development of a review protocol. The stages associated with conducting the review are: identification of research; selection of primary studies; study quality assessment; data extraction and monitoring; and data synthesis. Reporting the review is a single stage phase. Each phase is discussed in detail in the following sections. Therefore, this study adopted a retrieval method to obtain the relevant literature and constructed a model graph according to the research question to guide the analysis (Fig. 1).

Search strings and inclusion criteria

To attain a comprehensive understanding of relevant methods for pre-service teachers' CT training, we have systematically obtained relevant literature from literature databases and other channels.

First, the main sources of literature were as follows: a. Academic databases: Web of Science, Science Direct, and Google Scholar, among others. b. Related academic journals and conference papers, such as *Journal of Research on Technology in Education* and *Journal of Educational Computing Research*. c. Publications by scholars who have published research in the field of computer science education; d. Existing meta-analysis and literature review references.

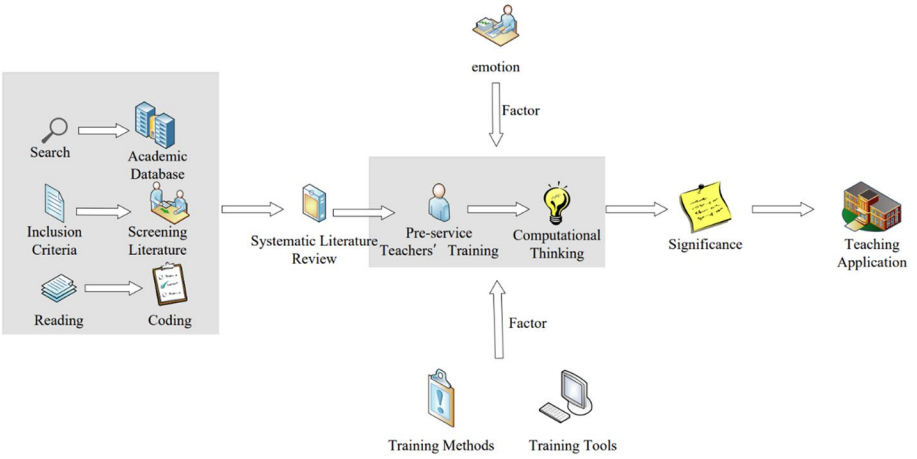


Fig. 1 Systematic literature review model diagram

Search keywords included pre-service teachers, CT, and pre-service teacher training. The specific search formulas included the following:

- (Pre-service teachers OR future teachers) AND (CT)
- (Teacher training) AND (CT)
- (Pre-service teacher training OR future teacher training) AND (CT)

Second, the time range of the literature search was set from 2011−2021, comprehensively considering the development of the CT and pre-service teacher education. The idea of CT was first introduced by Papert (1996). Later, prompted by a growing community of researchers, educators, and policymakers, CT as a concept and associated research agenda has witnessed increasing attention and investigation (Grover & Pea, 2013).

However, previous studies on CT have largely focused upon students (Barr & Stephenson, 2011; Grover & Pea, 2013; Yadav et al., 2011). However, studies do not often focus on teachers' perspective, and there is scant research that has systematically and comprehensively examined the influence of CT on pre-service teachers (Yadav et al., 2011). Owing to the retrieval strategy and inclusion criteria, the earliest published year of the included study was 2011. From 2011 to 2021, the number of CT studies on pre-service teachers showed an overall increasing trend. The quantity and quality of research on pre-service teachers' CT during this period is also more representative. Therefore, this time span was adopted as the scope of literature retrieval in this study.

Moreover, for a more comprehensive understanding of existing research on pre-service teachers' CT and to facilitate analysis and research, we refined the inclusion and exclusion criteria for samples in the literature review; the inclusion criteria were as follows:

(1) To ensure the academic type and standardisation of the article, the article must be peer-reviewed to exclude unpublished papers or dissertations;
(2) To ensure that the included literature is comprehensive, articles must cover different databases, journals, authors, and years;
(3) The participants must be pre-service teachers, and the status quo or post-intervention level of pre-service teachers' CT ability must be explained in the study;
(4) Research should put forward effective methods, tools, or reference suggestions for improving pre-service teachers' CT ability

The exclusion criteria were as follows:

(1) Exclude non-English literature and those in which pre-service teachers were not the subjects;
(2) Exclude literature with incomplete experimental data.

According to the above search methods, 562 related papers were retrieved, including 531 from academic databases and 31 from other sources. After removing the duplicate literatures (25) obtained during the search, 537 related literatures remained. Finally, according to the inclusion and exclusion standards, 537 related literatures were further analysed and screened, and 38 related literatures were identified. Figure 2 summarises the search procedure used to collect, assess, and analyse empirical evidence related to the research objectives.

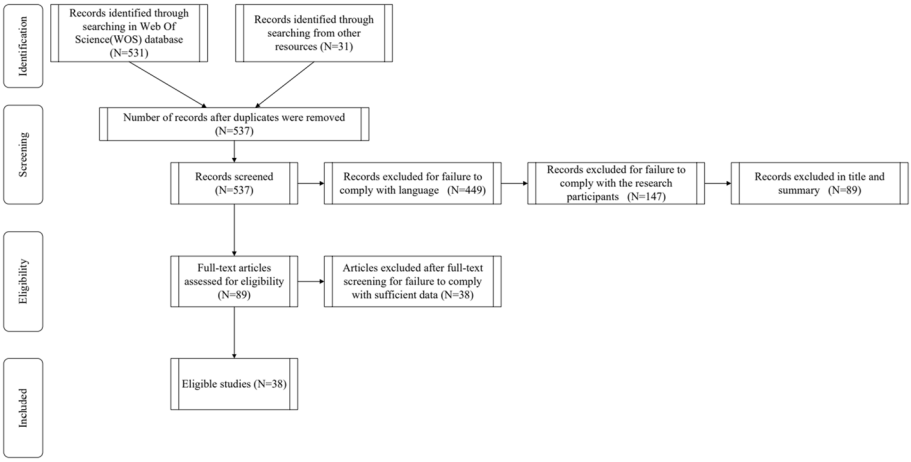


Fig. 2 PRISMA flow diagram of the article screening process

Data analysis

Considering the influence of different factors on the training process of pre-service teachers' CT, factors involved in the relevant literature were summarised to discuss their effects on the improvement of CT. In addition, this study tried to construct a development model for promoting pre-service teachers' CT ability guided by system theory. System theory holistically considers the system as the object, comprehensively studies the system and the relationship between the elements of the system, and essentially explains its structure, function, behavior, and dynamics to grasp the entire system and achieve the optimal goal (Bertalanffy, 1969). The theory mentions a feature called wholeness, which suggests that the whole is more than the sum of its parts, and the whole is greater than the sum of its parts, both quantitatively and qualitatively (Shaked & Schechter, 2014). A systematic literature review was conducted for 38 literatures, and the following process was used: Step 1. Overall induction was made for all samples of articles, and elements to be analysed were extracted, including research methods, training methods, training tools, and emotional factors. Step 2. Based on step 1, all elements were analysed and summarised, and the publication year, country, research methods and training methods of the literature were comprehensively described and analysed to form charts. This contributes to a systematic understanding of existing research on pre-service teachers' CT. Then, according to the descriptive statistics done before, the training methods of pre-service teachers' CT, aspects of CT ability, and influencing factors were cross-compared and analysed to answer the relevant research questions. Step 3. After further analysis of the elements mentioned in this study, and synthesisng all the conclusions, a model and reference suggestions for training pre-service teachers' CT were drawn.

Data distribution

Figure 3 shows the publication of papers on pre-service teachers' CT between 2011 and 2021, with an analysis for the year of inclusion. Yadav, Zhou, et al. published the first article in 2011, proposing to embed CT modules in the compulsory curriculum of

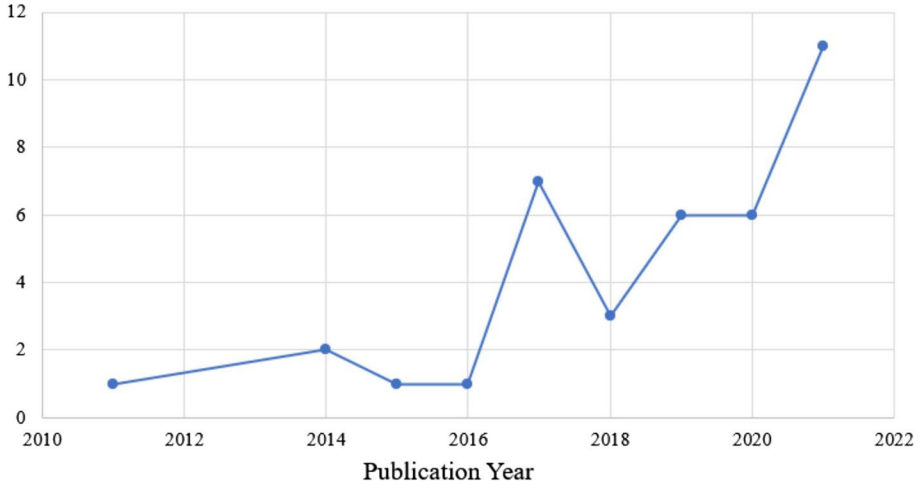


Fig. 3 The annual distribution of papers

primary and secondary education majors (Yadav et al., 2011). From 2011 to 2021, the number of articles on the training of pre-service teachers' CT showed an upward trend, with a significant increase in 2017 as the node. Previously, efforts to expose teachers to CT focused more on the professional development of in-service teachers; however, there was limited work on how to improve the CT of pre-service teachers and embed CT in future classrooms (Lamprou et al., 2017; Yadav et al., 2017). Scholars have recognised the importance of enabling prospective teachers to integrate CT into K-12 classrooms; moreover, research on preservice teachers to examine their current knowledge and how to best prepare them has been increasing (Sadik et al., 2017). So that could also be a reason for nodes in 2017. Although some fluctuations occurred, CT training of pre-service teachers attracted increasing attention in recent years. In the early stage, CT training was aimed at K-12 students, but research has gradually altered the perspective and focus of CT training to the training of teachers. Additionally, after pre-service teachers were trained on CT, they demonstrated a positive attitude toward the integration of CT into future teaching and were more likely to involve their students in CT activities to better improve students' CT ability (Cutumisu & Guo, 2019). Angeli et al. (2016) proposed the concept of TPACK for designing CT, such that teachers could teach independent CT courses. Some scholars proposed using CT as a means to explore subject contents and to embed CT knowledge and skills in the course, thus helping students acquire knowledge and solve problems (Mouza et al., 2017). Relevant policies in various countries also started focusing on developing pre-service teachers' CT.

Figure 4 illustrates the distribution of studies on CT training of pre-service teachers in each country to identify countries with more frequent publications. The nationality information of the first author of a research is listed in this study. Figure 4 shows that many countries have started exploring CT training for pre-service teachers. The distribution of the top three countries were as follows: the United States (14), Turkey (6), and Spain (4). Additionally, 28 articles were published in journals while 10 were conference papers published in proceedings.

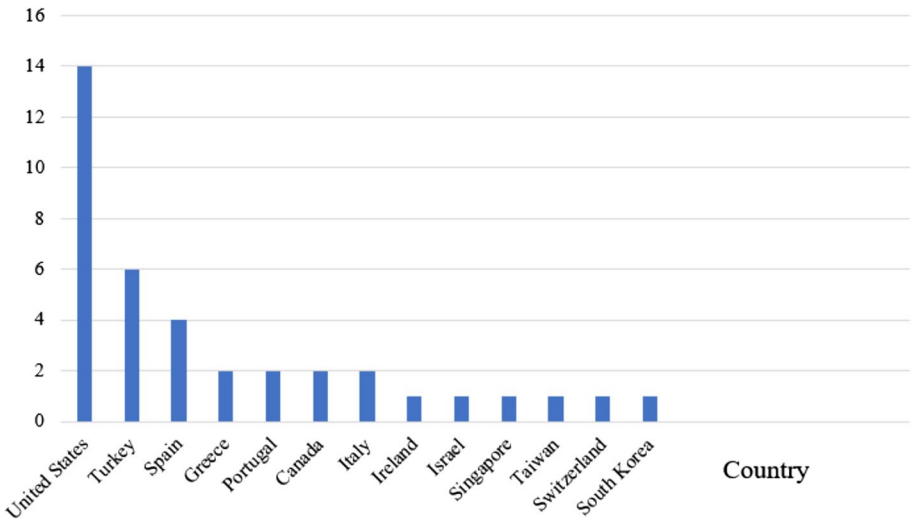


Fig. 4 The number of studies published by countries

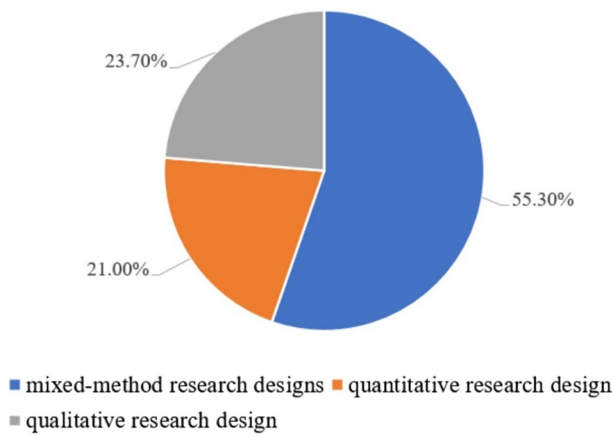
Results

Statistical description and distribution of studies

Distribution by research methodologies used in the studies

The research methods used in studies included research types, specific design, samples, data collection, and data analysis (Tashakkori, 2009). Appendix A presents a detailed summary of the research methods、analysis method and so on. Figure 5 shows the results of the analysis method presented in Appendix A.

Fig. 5 Research Methodologies Used in the Studies



First, the mixed method (55.3%) is the most used research method in the analysed studies, followed by qualitative method (23.70%) and quantitative method (21.00%). In terms of a specific type of study design, "design-based research" method was mentioned most frequently (80.95%), while "exploratory" (14.29%) and "explanatory" (4.76%) methods were mentioned in mixed method design. In this study, quantitative research design type refers to non-experimental and quasi-experimental or experimental designs, whereas qualitative research design involves 'case design'.

Second, the research objects were K-12 pre-service teachers who taught a range of subjects, including information technology, mathematics, biology, physics and so on. Studies have shown that all scientific disciplines, including biology and physics, can benefit from introductory courses in CT (Ateşkan & Hart, 2021). Thus, recent research on the cultivation of pre-service teachers' CT has involved multiple disciplines.

Additionally, sample sizes were analysed, revealing that the 38 studies had sample sizes ranging from 1 to 650, of which 23, 10, and 5 studies had sample sizes ranging from 1 to 99, 100 to 199, and 200 or more, respectively. Thus, the sample size of approximately half of the included studies was less than 100, indicating that the universality of the research results should be further verified. The small sample size may be attributed to limitations such as time and resources to conduct the studies; moreover, a few studies were conducted during an unexpected global pandemic (COVID-19), which may have affected the scope of the study (Bouck et al., 2021; Zha et al., 2020).

Furthermore, the data collection methods used in the 38 literatures varied between the research methods employed. Generally, each research used two or more data collection methods, with 'scale', 'questionnaire', and 'survey' being the most used quantitative data collection methods and 'interview' and 'open question' being the most used qualitative data collection methods. Other data collection methods are included field recordings, activity logs, classroom observations, and empirical reflection and feedback. The diversity of data sources verified the accuracy of research results.

Regarding data analysis, analysis methods, such as basic descriptive statistics and T-test, were generally adopted in quantitative data collection. Descriptive statistics are specific methods used to calculate, describe, and summarise collected research data in a logical, meaningful, and efficient manner (Vetter, 2017). A T-test is a statistical test used to compare the means of two groups. It can be divided into independent T-test (the two groups under comparison are independent) and paired T-test (the two groups under comparison are dependent on each other) (Kim, 2015). The qualitative data were generally analysed using content analysis a method of interpreting content data through a systematic classification process of coding and identifying themes or patterns (Hsieh & Shannon, 2005). In previous studies, the mean and standard deviation were usually used for descriptive analysis of the collected data (Ateşkan & Hart, 2021; Looi et al., 2020; Yadav et al., 2011). The T-test mainly applies to the case of small sample content to compare whether the difference between two values is significant. When the research needs to collect and analyse the data of pre-service teachers before and after the intervention, the T-test can be used to test the differences between pre-service teachers in some aspects before and after the intervention (Bean et al, 2015; Kalogiannakis & Papadakis, 2017; Mouza et al., 2017). In addition, content analysis processes were used to code the open-ended responses (Yadav et al, 2017). Appendix A presents a detailed summary of the analysis method. Regarding data analysis tools, additionally, SPSS software was used for quantitative data processing, while NVIVO software was used for qualitative data processing.

Description and Distribution by teacher's level of CT after intervention

The current CT level of pre-service teachers who did not participate in relevant training and the changes of CT of pre-service teachers after a series of intervention measures were analysed. Among the published studies, except for studies involving K-12 pre-service teachers with relevant experience, the participants in other studies did not have relevant knowledge and were not familiar with CT. After training, teachers were interviewed with open-ended questions or a questionnaire to evaluate the changes in their related knowledge, attitude, and self-efficacy. We found that teachers' self-efficacy, positive emotions, teaching improvement and other aspects were significantly improved (Yadav et al., 2014; Zha et al., 2020). Significant improvements were observed in the CT of pre-service teachers, such as concept understanding of CT, problem solving, algorithm thinking, programming or coding skills, critical thinking, creative thinking, decomposition, abstraction, and debugging. More than 60% of the studies mentioned specific aspects of pre-service teachers' CT. Figure 6 shows the proportion of specific aspects of pre-service teachers' CT ability. The results showed that concept understanding of CT had the highest proportion among the specific aspects mentioned (22.45%), followed by problem solving ability (21.43%), programming or coding ability (17.35%), and algorithm thinking ability (13.27%); however innovative thinking ability was the least mentioned aspect (2.04%). Thus, relevant methods of training focused more on the application ability and understanding of basic concepts and less on the cultivation of abstract thinking ability to improve CT of pre-service teachers, which should be considered in future studies.

Description and Distribution by training methods

Appendix B summarises pre-service teachers' CT training strategies, including training methods and tools. Six training methods were identified in 38 studies to promote CT in pre-service teachers: CT modules, CT courses, CT projects, educational robotics,

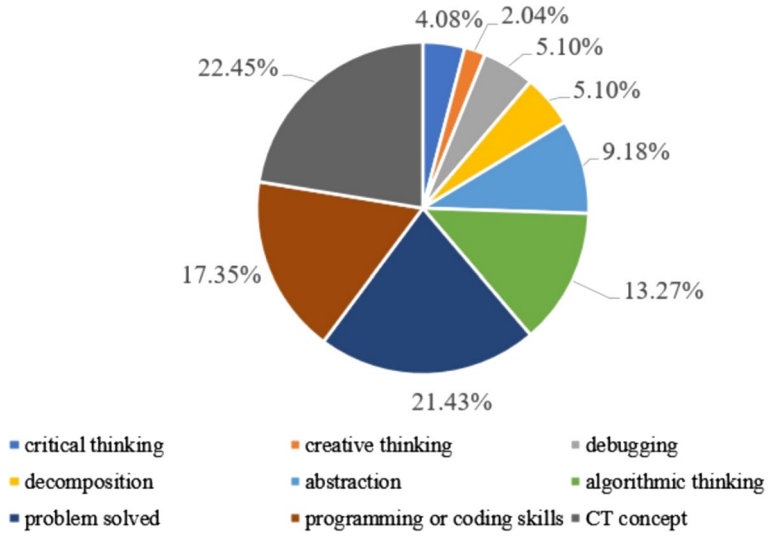


Fig. 6 CT's specific aspects in the studies

Table 4 Emotional factors considered in research studies

Emotional factors	No. of research studies
Attitude	14
Self-efficacy	10
Confidence	8
Interest	6
Will	3

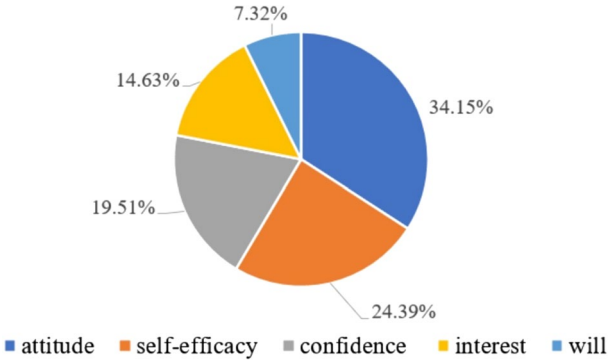


Fig. 7 Emotional factors in the studies

CT seminars, and programming application. Additionally, programming tools were mentioned in 27 studies, and Scratch programming language was the most used tool, with applications in 16 of 27 studies. Moreover, seven of these articles used more than two programming tools. For each article, Appendix B provides the following attributes in six columns: (a) reference of the paper, (b) sample, (c) age or level, (d) training method, (f) CT's specific aspects, and (g) programming tools.

Description and Distribution by emotional factors

The factors influencing the CT of pre-service teachers were analysed. Through the summary of relevant studies, we found that 27 mentioned the relationship between pre-service teachers' emotional factors and CT. Emotional factors, such as pre-service teachers' attitude toward training methods, self-efficacy, interest, and confidence in learning to apply CT, played an important role in the research process, and the implementation of these interventions will also affect the changes of pre-service teachers' emotional factors. Table 4 summarises the emotional factors mentioned in the study. Five emotional factors are listed: attitude, self-efficacy, interest, will, and confidence. As shown in Fig. 7, attitude and self-efficacy of pre-service teachers account for a large proportion of emotional factors. Research shows that a vast majority of pre-service teachers in the study actively cultivate CT, which is reflected in specific practical activities. Additionally, only a few studies mentioned other factors, such as gender, subject background, and age. Thus, this study did not include such factors among the list of influencing factors.

The influence of training methods on pre-service teachers' CT and emotional factors

Different methods promote different aspects of CT abilities

Table 5 shows how CT abilities are promoted by different cultivation methods. Owing to the lack of relevant studies on some cultivation methods, the analysis results did not have good representativeness. Therefore, Fig. 8 only selects the data of the top four studies for the analysis. According to Fig. 8, CT courses have the most significant effect on promoting programming or coding ability (24.24%), followed by problem solving skills (21.21%) and understanding of CT concepts (18.18%). Programming application mainly promotes the programming or coding ability (22.73%) of CT, suggesting that such a training environment is suitable for developing programming ability. Additionally, it was observed that CT courses and programming applications comprehensively cultivated CT ability. Recently, these methods have been widely used to develop CT ability of pre-service teachers. Furthermore, ER training programs were found to promote problem-solving skills, while the understanding of CT concepts and programming or coding skills showed equal results (21.43%). Similarly, CT module was found to promote pre-service teachers' problem-solving ability, understanding of CT concepts, and programming or coding ability. However, compared with other training methods, CT modules caused more significant improvements in critical thinking, indicating that the introduction of a CT module in professional courses could enable pre-service teachers to think more deeply about integrating CT into learning and application while continuing to learn from their professional courses. However, the overall data showed that the methods focused more on improving relevant computing abilities, involving computing practice, and less on promoting computing perspectives (Brennan & Resnick, 2012). In other words, current studies on the cultivation of pre-service teachers' CT ability paid more attention to their basic abilities such as development of concepts, while higher-order thinking skills, such as abstraction and creative thinking ability, were rarely focused upon.

Different methods promote different emotional factors

Table 6 summarises the distribution of emotional factors under different cultivation methods to further study the differences in various studies. As the analysis results do not have good representativeness owing to the lack of relevant studies on cultivation methods, Fig. 9 only selects the top four data to summarise and present the analysis. The self-efficacy of pre-service teachers accounts for the largest proportion in CT courses. Relevant studies showed that after receiving professional training in CT courses, the self-efficacy of pre-service teachers on CT ability has been significantly improved (Bean et al., 2015). Teachers with higher self-efficacy showed higher cognitive ability of the course (Dağ, 2019). Programming application have a significant impact on the attitude of pre-service teachers. This study showed that pre-service teachers have a positive attitude towards this method, which is conducive to the improvement of their CT ability. ER training projects mostly affect teachers' self-efficacy, followed by their interest. Through the operation of educational robots, pre-service teachers could better stimulate their interest in learning, thereby improving their CT ability. Moreover, the influence of CT module on pre-service teachers was relatively balanced, affecting pre-service teachers' attitude, self-efficacy, interest, and willingness to use CT in future teaching. Furthermore, CT courses, programming applications, and ER intervention had an impact on teachers'

Table 5 The specific situation of different training methods to promote different aspects of CT abilities

CT's specific aspects/training methods	CT course	Programming application	The educational robotics intervention	CT module	CT project	CT seminar
Critical thinking	1	1	0	2	0	0
Creative thinking	1	1	0	0	0	0
Debugging	1	2	1	0	1	0
Decomposition	3	1	1	0	0	0
Abstraction	2	2	2	3	0	0
Algorithmic thinking	4	2	1	1	1	1
Problem solved	7	4	3	4	1	1
CT concept	6	4	3	5	4	0
Programming or coding skills	8	5	3	4	1	1

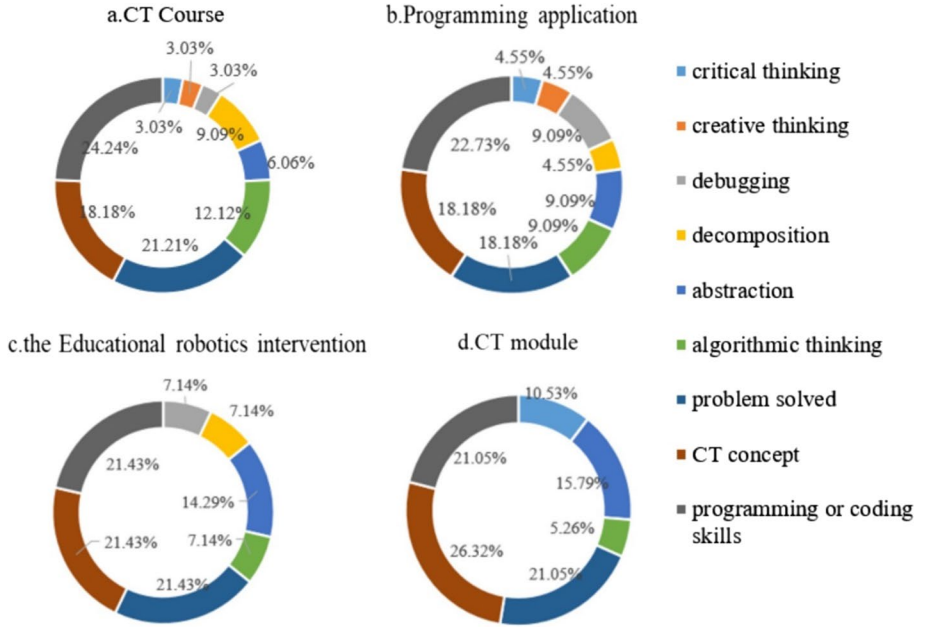


Fig. 8 The proportion of specific aspects of CT in different training methods

Table 6 The specific situation of different training methods to influence different emotional factors

Emotional factors/ Training methods	CT course	Programming application	The educational robotics intervention	CT module	CT project	CT seminar
Attitude	2	4	0	1	0	0
Self-efficacy	4	2	3	1	0	0
Confidence	4	1	2	0	1	0
Interest	2	0	2	1	1	0
Will	1	0	1	1	0	0

confidence; that is, pre-service teachers were more confident in using CT in future teaching after relevant training. The overall data shows that different training methods have different effects on the emotions of pre-service teachers. Therefore, the influence of emotional factors should be considered when developing training for pre-service teachers to facilitate active learning and application of CT skills.

Discussion

At present, the CT of pre-service teachers has been gaining increasing attention in various countries. This study conducted a systematic literature review and analysed various studies on the promotion of CT among pre-service teachers. These studies (28 articles + 10 conference

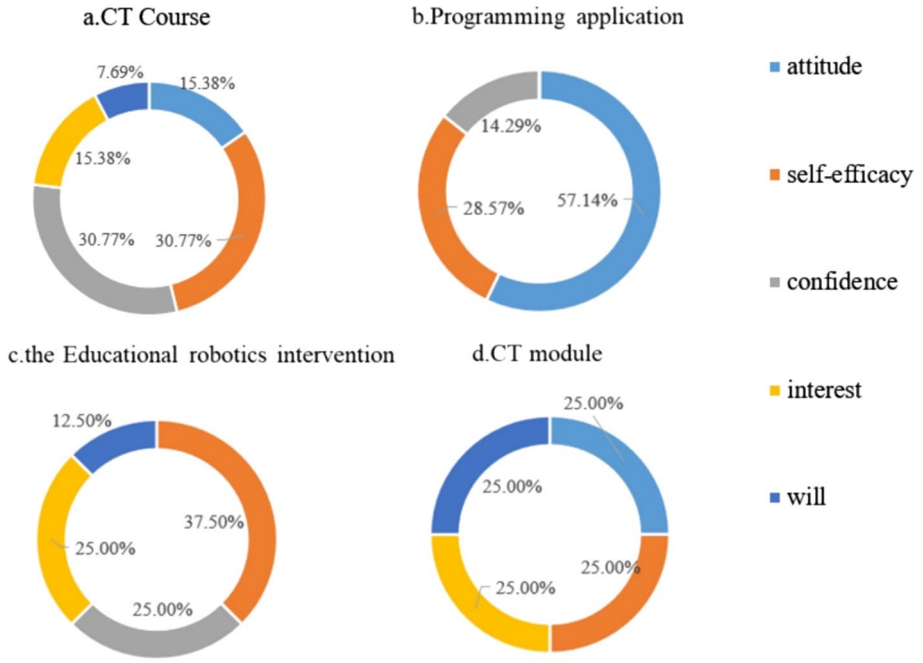


Fig. 9 The proportion of emotional factors in different training methods

papers) satisfied the criteria to be included in the analysis. A total of 38 studies were then reviewed and the research questions answered.

RQ1: What research methods were used in previous studies?

In this study, the mixed research method was found to be the most used research method in 38 studies. Mixed research method refers to 'the intentional integration of quantitative and qualitative research methods to better solve research problems' (Clark & Ivankova, 2016). This result is reasonable because the mixed research method considers a research problem more comprehensively compared with a quantitative or qualitative method. This approach generates additional insight and understanding that may be difficult to achieve when using only a single paradigm (Johnson & Onwuegbuzie, 2004). This research method can provide a more comprehensive and multi-perspective understanding of complex educational phenomena and problems. A combined analysis of qualitative and quantitative data can help attain a broader and deeper solution to the problem, thus providing more accurate references and suggestions for practice and application. Data collection and analysis can enable accurate conclusions about the status quo of pre-service teachers' CT ability and the changes after intervention, thus facilitating future research and intervention designs.

RQ2: In previous studies, what methods were used to promote pre-service teachers' CT?

Pre-service teachers lack a comprehensive and systematic understanding of computer-aided instruction; moreover, they lack confidence in the application of computer-aided instruction in future teaching. Additionally, some pre-service teachers developed a misunderstanding regarding CT, believing that CT could only be applied using computers, including using computers to solve problems or equating CT with programming. Pre-service teachers had limited understanding of CT before receiving training, which prevented them from embedding CT in future classes, thus affecting students' learning of CT (Bower & Falkner, 2015).

After receiving training, the CT ability of pre-service teachers significantly improved, which was reflected in their better understanding of CT concepts, critical thinking, innovation abilities, abstraction abilities, and so on (Pala & Mıhçı Türker, 2021; Saez-Lopez et al., 2020). Overall, interventions in 38 studies were found to be effective based on pre- and post-trial data presented in the literature.

According to the review of relevant studies, six effective interventions improved CT of pre-service teachers: CT course, CT module, CT project, ER intervention, the programming application, and CT seminar. Developing relevant CT courses was the key method used to improve CT of pre-service teachers. CT courses were found to make pre-service teachers' learning more systematic and universal. CT courses also helped preservice teachers better understand CT concepts and practices and their applications in future classroom teaching (Mouza et al., 2017). However, CT courses have a few shortcomings. For example, the course pays more attention to theoretical learning, but there are certain limitations in application. Therefore, in addition to CT courses, studies have also proposed other effective interventions, such as programming applications and robotics teaching and other interventions based on physical tools. These methods could help build a more effective learning environment for pre-service teachers, translate the theoretical knowledge learned into classroom practice, and create new teaching activities (Piedade et al., 2020). Some studies have also attempted to embed CT modules into the professional learning of pre-service teachers to enable teachers to better integrate CT with teaching (Bean et al., 2015). This method benefitted from the combination of CT with teachers' professional courses, rather than learning CT as an isolated individual. Therefore, pre-service teachers could integrate CT into future teaching and obtain a better understanding of the combination of CT with the discipline. If CT module could be introduced into teacher education curriculum, it would reduce the learning burden of pre-service teachers. Few studies suggested other approaches such as seminar learning and project-based interventions to cultivate teachers' CT. Overall, most teachers responded positively to the intervention and realised that CT was effective for computer science teachers, while being relevant to their profession.

Furthermore, some studies mentioned programming languages and environments used in interventions, such as Scratch and Code.org. These visualisation tools could help participants conduct more effective explorations and acquire relevant knowledge (Cutumisu & Guo, 2019). As beginners are not required to follow strict grammar rules to write code, programming in Scratch was easier and more suitable for pre-service teachers who were undergoing training. Therefore, Scratch was found to account for a large proportion among all interventions used in relevant studies, revealing that it could help develop learners' CT (Topalli & Cagiltay, 2018). In addition, a study has shown that the use of C++programming language in programming education does not seem to impact the overall CT skills of pre-service teachers (Pala & Mıhcı Türker, 2021). In other words, abstract programming languages will make it difficult for pre-service teachers to understand and learn CT. Over-structuring the programming process can also obscure deeper CT.

Notably, 10 studies combined CT courses with Scratch to improve CT of pre-service teachers. Through the learning of curriculum theories and specific operations and applications of Scratch, pre-service teachers could better understand the application of CT. In summary, we analysed and summarised previous studies, as well as mentioned six intervention methods (see Appendix B).

RQ3: What were the main factors interacting with pre-service teachers' CT in previous studies?

The analysis of relevant studies revealed that some emotional factors such as the attitude, interest, and self-efficacy of pre-service teachers interacted with CT, influencing teachers' CT ability.

A total of 27 studies mentioned the relationship between affective factors and CT. This study summarised five main affective factors: attitude, self-efficacy, interest, willingness, and confidence. Among them, attitude and self-efficacy of pre-service teachers were found to play an important role. Studies have shown that CT attitude can predict CT skills (Cutumisu et al., 2021). The attitude of pre-service teachers toward intervention directly affected learning. Thus, pre-service teachers were more likely to change their attitude toward CT for a more effective learning process. Additionally, relevant studies have shown that teachers with a good sense of self-efficacy were more active in learning and had a better understanding and perception of relevant interventions (Dağ, 2019). After the intervention, most of the teachers showed positive attitudes toward the learning and application of CT (Ateşkan & Hart, 2021). Simultaneously, the improvement of pre-service teachers' CT also enhanced their willingness to incorporate CT into future teaching and confidence in using CT. Therefore, follow-up research should pay more attention to the emotional changes of pre-service teachers and conduct more targeted and effective training. Finally, a few studies also mentioned that the gender of pre-service teachers and their subject background might affect CT. However, due to the small number of samples and lack of empirical support, this study did not include these factors in the analysis. Subsequent studies could conduct more detailed exploration and analysis considering these factors.

RQ4: How does one establish the development model of pre-service teachers' CT with existing training methods?

In light of the above, guided by system theory, this study constructed a development model for promoting pre-service teachers' CT ability while considering CT abilities, intervention methods, and tools (Fig. 10). This model aimed to develop CT of pre-service teachers and laid a foundation for future application of CT in teaching. Based on the previous research, we summarised the general elements of pre-service teachers' CT training, combined with the holistic theory of system theory, and integrated them to form a complete system development model. From the perspective of system theory, the model of pre-service teacher competence development is composed of many interrelated elements, which requires comprehensive consideration of CT method, CT practice and improvement method.

As per the system theory, according to existing research preservice teachers calculation based on the training mode of thinking, pre-service teachers' CT ability development model is a system, with intervention by CT, practices, and methods to improve as the three main elements. CT intervention as a foundation, CT practice is the carrier and method of improvement is the direction; they effect and influence each other to train pre-service teachers' CT ability. This model (see Fig. 10) focuses on improving the CT ability of pre-service teachers, which covers various teaching intervention elements extracted from the results of previous research. It is necessary to design teaching intervention according to pre-service teachers' existing level of CT. Although

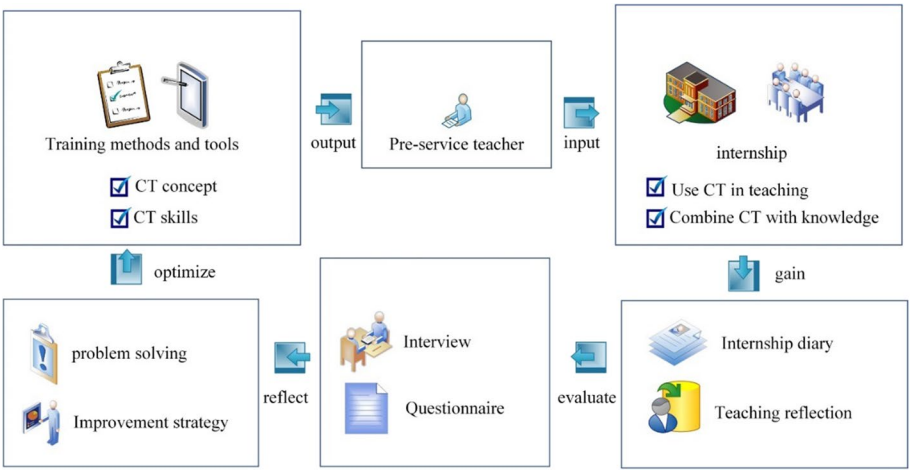


Fig. 10 New model for developing computational thinking

some existing studies do not report it as a dimension, all of them mention the relevant background of pre-service teachers before intervention. The existing CT level of pre-service teachers as their background will have an important impact on the subsequent teaching intervention, practice, and improvement. In addition, all included studies carried out systematic CT intervention on the participants and achieved certain effects. Therefore, intervention is the starting point of the model. According to the analysis of this study, 6 training methods are summarised. Teachers of different levels can determine training methods to improve their CT ability as per their own contexts. The second stage of the model is the practice of pre-service teachers. After mastering certain CT knowledge and skills, K-12 pre-service teachers enter local primary and middle schoolsas interns to output the knowledge and skills they have acquired, while learning to combine CT with professional knowledge in specific teaching practices. The findings will enable preservice teachers to apply CT to future teaching. The third stage is the reflection and practice log of the pre-service teachers in K-12 teaching practice, that is, the CT ability is transferred to a wide range of teaching fields and is improved from the practice. The analysis of teaching reflection and other materials can also be collected through interviews and surveys with pre-service teachers to obtain specific data and content, find defects and problems existing in the training, and further improve pre-service teacher training of CT to perfect the training system. Designers can further improve the training according to the relevant materials provided by the pre-service teacher internship. Pre-service teachers can also enhance the teaching process based on student feedback. This model forms a closed-loop system, which makes the improvement and application of pre-service teachers' CT ability more systematic and structured.

Limitations and next steps

First, to determine the number of studies and research scope, we used the retrieval method to search and screen previous studies. However, many relevant studies were excluded because they did not meet the inclusion criteria, which limited the number of studies. With the continuous expansion and updating of relevant studies, the inclusion criteria could be further divided to ensure the comprehensiveness of the search. Additionally, this study focused on studies in English, but expansion of the language range to include Korean,

Spanish, and other languages is suggested to obtain comprehensive results. Third, we found that some relevant studies did not give a detailed description of their basic information and did not control any variables that might have an impact. For example, a few studies did not provide participants with complete information, such as subjects, ages, and study periods. Therefore, in this study, we did not conduct a more detailed review of the factors in the research process, and only focused on research methods, training methods, and emotional factors. The range of factors should be expanded in future studies to obtain more specific and reliable conclusions. Finally, the current research did not develop a systematic method for improving pre-service teachers' CT, and some studies used incomplete designs. However, studies have focused on the CT of special education teachers. This indicates that although the current research is not perfect, the research object is gradually expanding.

Thus, based on the above findings, the following suggestions are provided for the future design of CT research for pre-service teachers: (1) The differences in cognitive abilities of pre-service teachers of different ages, genders, and disciplines called for diversity in the cultivation methods, content standards, and learning methods of CT ability. CT training courses should be designed or combined according to different situations, and appropriate methods should be adopted for training. (2) Training should provide appropriate help or feedback for different pre-service teachers and different marking criteria. Such evaluation would also be helpful for the design and modification of future activities. (3) In future studies, the sample size could be appropriately expanded, and the study group coverage could be widened to obtain more general conclusions.

Finally, this study developed a new CT training model, but it lacked more specific practice. Thus, this model could be used as a reference for research and encourage researchers and teachers to conduct more detailed exploration of practice. It is believed that this study would help improve the CT of pre-service teachers.

Conclusion

This study systematically reviewed relevant studies on the CT training of pre-service teachers. During the analysis, research methods, cultivation methods, tools, and emotional factors were extracted, and six cultivation methods and five influence factors were summarised. Furthermore, the cultivation methods and related factors were examined, and reference suggestions were proposed to provide better reference for researchers in the future. Finally, a CT ability training model was constructed. Pre-service teachers and researchers could conduct practical exploration according to the model, which might be more conducive to improving CT ability of pre-service teachers. In general, this study summarised the CT training design and created a training model for K-12 pre-service teachers to further improve their CT ability.

Appendix A

See Table 7.

Table 7 Articles and study methods

Article	Study type	Analysis method	Study specific design	Data collection
Yadav et al. (2011)	Mixed-method research design	Basic descriptive statistics and content analysis	Design-based research	Quantitative and qualitative methods consisted of open-ended and multiple-choice questionnaires
Yadav et al. (2014)	Quantitative research design	Two-way univariate analysis of variance (ANOVA)	Quasi-experimental design	The quantitative methods consisted of Computational Thinking Quiz and Computing Attitude Questionnaire
Perez et al. (2014)	The qualitative research design	Content analysis	Case study	The qualitative methods consisted of the participants'immediate feedback
Bean et al. (2015)	Quantitative research design	A one tailed paired t-test	Non-experimental design	The quantitative methods consisted of Teachers' Self-Efficacy in Computational Thinking (TSECT)and Self-Efficacy for Computational Thinking (SECT)
Cetin (2016)	Mixed-method research design	An independent sample t-test analysis and content analysis	Exploratory	The qualitative methods consisted of a semi-structured interview. The quantitative methods consisted of an achievement test, a practice test, and a computer programming attitude scale
Kalogiannakis, and Papadakis (2017)	Mixed-method research design	Basic descriptive statistics and content Analysis	Design-based research	The qualitative methods consisted of semi-structured interviews. The quantitative methods consisted of questionnaires
Song (2017)	Mixed-method research design	basic descriptive statistics and content analysis	Design-based research	Quantitative and qualitative methods consisted of questionnaire
Estebanell Minguell et al. (2017)	Mixed-method research design	Basic descriptive statistics and content analysis	Design-based research	Quantitative and qualitative methods consisted of questionnaire

Table 7 (continued)

Article	Study type	Analysis method	Study specific design	Data collection
Jaipal-Jamani, and Angeli (2017)	Quantitative research design	Basic descriptive statistics and statistical tests	Non-experimental design	The quantitative methods consisted of pre-tests and post-tests on science content, prequestionnaires and postquestionnaires for interest and self-efficacy, and four programming assignments
Yadav et al. (2017)	Qualitative research design	Content analysis	Case study	The qualitative methods consisted of questionnaire
Mouza et al. (2017)	Mixed-method research design	Basic descriptive statistics、t-tests and the constant comparative method	Design-based research	The qualitative methods consisted of a self-reported survey and case reports. The quantitative methods consisted of survey
Sadik et al. (2017)	Qualitative research design	Content analysis	Case study	The qualitative methods consisted of preservice teachers' initial proposals, two blog posts, video recordings of in-class discussions, instructional materials, final papers, and a long-term blog post 3 months after the intervention
Ragonis (2018)	Mixed-method research design	Content analysis	Design-based research	Quantitative and qualitative methods consisted of projects and papers
Lamprou and Repenning (2018)	Mixed-method research design	Effect size calculation and content analysis	Design-based research	Quantitative and qualitative methods consisted of questionnaire and in-depth interviews
Adler and Kim (2018)	Mixed-method research design	Basic descriptive statistics and content analysis	Design-based research	Quantitative and qualitative methods consisted of questionnaire, observations in the classroom and survey

Table 7 (continued)

Article	Study type	Analysis method	Study specific design	Data collection
Pala and Mıhçı Türker (2021)	Quantitative research design	Non-parametric tests	Quasi-experimental design	The quantitative methods consisted of Computational Thinking Scale (CTS)
Cutumisu and Guo (2019)	Qualitative research design	Topic modeling	Case study	The qualitative methods consisted of an up to 500-word reflection on their experience onto the Moodle-supported course
Papadakis and Kalogiannakis (2019)	Mixed-method research design	A t-test and content analysis	Design-based research	The qualitative methods consisted of semi-structured interviews. The quantitative methods consisted of pre-test/post-test quasi-experimental design
Gabriele et al. (2019)	Qualitative research design	Content analysis	Case study	The qualitative methods consisted of the Report elaborated by each team and the apps source files
Esteve-Mon et al. (2019)	Mixed-method research design	Basic descriptive statistics and content analysis	Design-based research	Quantitative and qualitative methods consisted of the Inventory of Competencies in Information and Communication Technologies (INCOTIC) and CT test
Dağ (2019)	Qualitative research design	Basic descriptive statistics, non-parametric test methods and content analysis	Case study	The qualitative methods consisted of general self-efficacy scale, self-efficacy scales for programming, and personal information form

Table 7 (continued)

Article	Study type	Analysis method	Study specific design	Data collection
Piedade et al. (2020)	Mixed-method research design	The Pearson correlation、the linear regression 、basic descriptive statistics and content analysis	Design-based research	Quantitative and qualitative methods consisted of focus-group interview, a self-reported scale,rubric for the assessment of programming fundamentals and CT skills and analysis of the learning scenario template designed
Looi et al. (2020)	Mixed-method research design	Basic descriptive statistics	Explanatory	Quantitative and qualitative methods consisted of survey
Sáez-López et al. (2020)	Mixed-method research design	t-tests and content analysis	Exploratory	Quantitative and qualitative methods consisted of the survey technique and a questionnaire
Zha et al. (2020)	Mixed-method research design	A t-test and content analysis	Design-based research	The qualitative methods consisted of answers to the open-ended question in the post-module survey and online discussion forums. The quantitative methods consisted of survey and quizzes
Enoch and West (2020)	Qualitative research design	Basic descriptive statistics and content analysis	Case study	The qualitative methods consisted of a post-instructional survey and teacher scores on learners' completed badges
Kaya et al. (2020)	Quantitative research design	The paired samples t-test	Non-experimental design	The quantitative methods consisted of Computational Thinking Teaching Efficacy Beliefs Instrument (CTTEBI) and Computational Thinking Teaching Outcome Expectancy (CTTOE) beliefs

Table 7 (continued)

Article	Study type	Analysis method	Study specific design	Data collection
Ateşkan and Hart (2021)	Mixed-method research design	Basic descriptive statistics 、 paired samples t-test and content analysis	Design-based research	Quantitative and qualitative methods consisted of an on-line pre- and post-attitude questionnaire and participants' WebQuest products and online discussion posts
Cutumisu et al. (2021)	Quantitative research design	Basic descriptive analysis and structural equation modeling	Non-experimental design	The quantitative methods consisted of the Callysto CT test (CCTt)
Butler and Leahy (2021)	Qualitative research design	Grounded theory methods	Case study	The qualitative methods consisted of reports of participants' classroom-based research and interviews
Connolly et al. (2021)	Quantitative research design	An independent sample t-test analysis	Experimental design	The quantitative methods consisted of the Computational Thinking Test
Piedade (2021)	Quantitative research design	The linear regression、an independent-sample t-test、one-way ANOVA test	Non-experimental design	The quantitative methods consisted of the self-report scale
Schina et al. (2021)	Mixed-method research design	Paired samples t-test、basic descriptive statistics and content analysis	Design-based research	The qualitative methods consisted of participants' training journals. The quantitative methods consisted of two post-questionnaires on pre-service teachers' acceptance and self-efficacy towards ER
Tsai et al. (2021)	Mixed-method research design	A paired-sample t-test and content analysis	Design-based research	The qualitative methods consisted of a self-developed questionnaire. The quantitative methods consisted of a s computational thinking test, a computer programming attitude scale, and an energy knowledge test

Table 7 (continued)

Article	Study type	Analysis method	Study specific design	Data collection
Uzumcu and Bay (2021)	Mixed-method research design	Basic descriptive statistics and content analysis	Design-based research	The qualitative methods consisted of graduation projects. The quantitative methods(OXO) consisted of the computational thinking related skill tests
Umutlu (2021)	Qualitative research design	Content analysis	Case study	The qualitative methods consisted of learning activities
Alqahtani et al. (2022)	mixed-method research design	a multivariate analysis of variance (MANOVA) and content analysis	Design-based research	The qualitative methods consisted of qualitative reflections. The quantitative methods consisted of a questionnaire
Bouck et al. (2021)	Mixed-method research design	Basic descriptive statistics and content analysis	Exploratory	Quantitative and qualitative methods consisted of preservice teachers' lesson plans and reflections

Appendix B

See Table 8.

Table 8 Sample articles, training methods and tools and specific aspects of promoting CT

Article	Sample	Age/level/gender	Training method	CT's specific aspects	Programming tools
Yadav et al. (2011)	100 preservice teachers	78 female and 22 male	CT module	Critical thinking problem solved CT concept	Not reported
Yadav et al. (2014)	357 preservice teachers	Control group: The average age of 20.5, sophomores (44.8%) and juniors (35.7%) Experimental group: The average age of 21, sophomores (44.7%) and juniors (36.2%)	CT module	Abstraction algorithmic thinking problem solved CT concept	Not reported
Perez et al. (2014)	320 preservice teachers	Not reported	CT course	Decomposition algorithmic thinking CT concept	Scratch
Bean et al. (2015)	116 preservice teachers	Not reported	CT course	problem solved programming or coding skills CT concept	Scratch
Cetin (2016)	56 preservice teachers	29 female and 27 male,19-27 years old, the average age of 21	Scratch	problem solved CT concept	Scratch C Programming Language
Kalogiannaki and Papadakis (2017)	122 pre-service teachers	122 female pre-service kindergarten teachers	ScratchJr	Programming or coding skills	scratchJr
Song (2017)	20 pre-service teachers	Not reported	CT course	Problem solved	Scratch
Estebanell Minguell et al. (2017)	320 preservice teachers	86% females, 14% males.116 students in the Primary and Early Childhood Education Degrees	CT project	CT concept	Not reported

Table 8 (continued)

Article	Sample	Age/level/gender	Training method	CT's specific aspects	Programming tools
Jaipal-Jamani, and Angeli (2017)	21 elementary preservice teachers	11 females and 10 males	The Educational robotics intervention	Abstraction algorithmic thinking	Not reported
Yadav et al. (2017)	134 preservice teachers	95 females and 39 males. 41 sophomores, 55 juniors, 29 seniors and 9 undisclosed. The average age of participants was 20.70	Not reported	Not reported	Not reported
Mouza et al. (2017)	21 preservice teachers	The average age of participants was 20	CT course	Decomposition Abstraction algorithmic thinking CT concept	Not reported
Sadik et al. (2017)	12 preservice teachers	primary majors in education	CT project	Algorithmic thinking problem solved programming or coding skills CT concept	Scratch scratchJr code.org
Ragonis (2018)	100 pre-service teachers	1.sciences for high school (38) 2.humanities and social sciences for high school (34) 3.various disciplines for elementary school (28)	CT course	Algorithmic thinking CT concept	scratch
Lamprou and Repenning (2018)	625 preservice teachers	Not reported	CT course	Programming or coding skills	Scratch Agent-cubes processing
Adler and Kim (2018)	32 preservice K-8 teachers	26 female and 6 male,19 were graduate students and 13 were undergraduate students	CT module	Abstraction problem solved CT concept	Scratch

Table 8 (continued)

Article	Sample	Age/level/gender	Training method	CT's specific aspects	Programming tools
Pala and Pınar Mıhçı Türker (2021)	33 preservice teachers	16 females and 17 males the department of Computer Education and Instructional Technology (CEIT)	The Arduino IDE platform and C++	Critical thinking creative thinking decomposition abstraction algorithmic thinking CT concept	Arduino c++
Cutumisu and Guo (2019)	139 preservice teachers	95 females, 43 males, and 1 undisclosed	CT course	Decomposition Abstraction algorithmic thinking problem solved programming or coding skills CT concept	cord.org moodle
Papadakis and Kalogiannakis (2019)	120 preservice teachers	99%females, 1% males	CT course	Problem solved programming or coding skills CT concept	scratch
Gabriele et al. (2019)	141 Italian pre-service teachers	128 females, 13 males. 18–40 years old	CT course	Critical thinking creative thinking problem solved programming or coding skills,	scratch
Esteve-Mon et al. (2019)	114 Spanish preservice teachers	64% females and 36% males. The average age of participants was 20	The Educational robotics intervention	Problem solved programming or coding skills CT concept	scratch
Dağ (2019)	26 pre-service teachers	Department of Computer Education of the Faculty of Education	CT course	Programming or coding skills	Scratch small basic alice
Piedade et al. (2020)	26 pre-service informatics teachers	57.6%% females and 42.4% males 22–56 years old	The Educational robotics intervention	Debugging CT concept algorithmic thinking	Not reported
Looi et al. (2020)	329 preservice teachers	208 of them were trained in teaching non-STEM subjects	CT seminar	Algorithmic thinking problem solved programming or coding skills	Not reported

Table 8 (continued)

Article	Sample	Age/level/gender	Training method	CT's specific aspects	Programming tools
Sáez-López et al. (2020)	79 pre-service teachers	72.2% females and 27.8% males	Scratch	Debugging problem solved programming or coding skills	scratch
Zha et al. (2020)	15 preservice teachers	14 females and 1 male. 13 majored in elementary education and 2 majored in secondary education	Hopscotch	problem solved programming or coding skills CT concept	Not reported
Hunsaker and West (2020)	40 preservice teachers	Not reported	CT project	Programming or coding skills CT concept	Not reported
Kaya et al. (2020)	35 preservice teachers	30 females and 5 males.21–61 years old and the average age of participants was 30	CT course	problem solved programming or coding skills	lego wedo
Ateşkan and Hart (2021)	45 preservice teachers	20–23 years old. 11 biology, 14 mathematics, 13 English Language and Literature and 7 Turkish Language and Literature pre-service teachers	CT module	Critical thinking abstraction problem solved CT concept	Not reported
Cutumisu et al. (2021)	105 preservice teachers	68 females and 37 males.17–54 years old	Not reported	Not reported	Not reported
Butler and Leahy (2021)	51 preservice teachers	18 participated in Year 1 (15 females and 4 males) and 24 in Year 2 (20 females and 4 males)	CT module	Problem solved CT concept	Scratch scratchjr
Connolly et al. (2021)	20 preservice teachers	65% females and 35% males, 18–19 years old	Educative mobile applications	Debugging CT concept sequencing	Not reported
Piedade (2021)	49 preservice teachers	25 females and 24 males.22–56 years old	The Educational robotics intervention	problem solved CT concept	Not reported
Schina et al. (2021)	90 pre-service preschool teachers	The average age of the participants was 22.9	The Educational robotics intervention	Not reported	Not reported
Tsai et al. (2021)	36 preservice primary teachers	30 females and 6 males	CT project	programming or coding skills CT concept	Scratch arduino

Table 8 (continued)

Article	Sample	Age/level/gender	Training method	CT's specific aspects	Programming tools
Ozlem and Bay (2021)	11 preservice primary teachers	7 females and 4 males	CT program	Debugging algorithmic thinking abstraction problem solved	Not reported
Umutlu (2021)	12 preservice teachers	education major	CT course	Debugging problem solved programming or coding skills	scratch
Alqahtani et al. (2022)	32 preservice elementary teachers	28 females and 4males	The Educational robotics inter-vention	Decomposition Abstraction algorithmic thinking problem solved programming or coding skills	Not reported
Bouck et al. (2021)	31 preservice special education teachers	30 female and 1 male	CT course	CT concept	Scratch

Declarations

Conflict of interest The authors declare no conflicts of interest.

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