Implementation and training of primary school teachers in computational thinking: a systematic review

Implementación y formación del profesorado de educación primaria en pensamiento computacional: una revisión sistemática

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ABSTRACT

Computational thinking encompasses mental processes that facilitate automated solutions to specific problems. Its integration into primary education is grounded in enhancing problem-solving skills and adapting to the digital environment. However, exactly what constitutes effective teacher training and classroom implementation strategies remains ambiguous. These concerns are addressed in this systematic review, highlighting the influence of school practices on shaping educational curricula. This research examines the implementation of computational thinking and teacher training at the primary education level. Initially, 428 studies were identified in Scopus and Web of Science, and these were then narrowed down to 24 empirical studies published between 2006 and 2023 after applying eligibility criteria and quality assessment. The findings indicate that many educators strive to incorporate computational thinking without adequate training. Robot programming prevails as the primary strategy, and there is high demand for training on the subject, but the use of "unplugged" activities is limited. Nevertheless, before computational thinking in primary education is advocated for, further research is warranted, particularly in the early grades. Educational institutions are encouraged to take the lead in designing and evaluating teacher training programs according to a set of guidelines provided. The successful integration of computational thinking into primary education necessitates more robust pedagogical approaches supported by appropriate teacher training.

Keywords: computational thinking; primary education; teacher training; initial teacher training; in-service teacher training.

RESUMEN

El pensamiento computacional engloba procesos mentales que propician soluciones automatizadas a problemas específicos. Su integración en la educación primaria se sustenta en la mejora de habilidades resolutivas y adaptación al entorno digital. No obstante, la formación del profesorado y las estrategias eficaces para su implementación en aulas son aún ambiguas. Estas inquietudes se abordan en esta revisión sistemática, destacando la influencia de la práctica escolar en la configuración de planes de estudio de educación. Esta investigación examina la implementación del pensamiento computacional y la formación del profesorado en la etapa de educación primaria. Inicialmente, se identificaron 428 estudios en Scopus y Web Of Science, reduciéndose a 24 estudios empíricos publicados entre 2006 y 2023 tras aplicar los criterios de elegibilidad y la evaluación de calidad. Los resultados indican que muchos docentes intentan incorporar el pensamiento computacional sin suficiente formación. La programación de robots prevalece como estrategia principal y es la más demandada en la formación, mientras que el empleo de actividades desconectadas es limitado. No obstante, antes de promover el pensamiento computacional en primaria, se requiere mayor investigación, especialmente en los primeros cursos. Se insta a las Facultades de Educación a liderar el diseño y evaluación de programas de formación del profesorado, ofreciéndose pautas al respecto. La integración exitosa del pensamiento computacional en educación primaria demanda enfoques pedagógicos más sólidos respaldados por una formación docente adecuada.

Palabras clave: pensamiento computacional; educación primaria; formación de profesores; formación inicial del profesorado; formación permanente del profesorado.

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INTRODUCTION

Computational thinking (CT) is increasingly present in various educational systems. The more intuitive technological developments and the supposed benefits of its development make it an essential competence (González et al., 2018). Wing (2006) defined CT as a thinking process based on computational concepts that enables problem solving and system design. Following Wing's publication, research in this area experienced a growing increase. However, studies addressing teacher training and pedagogical approaches to CT teaching and learning remain scarce. Most focus on measuring CT (Haseski & Ilic, 2019) and reflect the lack of consensus on its definition and components (Bocconi et al., 2016; Hsu et al., 2019; Moreno-León et al., 2019; Román-González et al., 2017; Segredo et al., 2017; Shute et al., 2017).

Aware of the need for agreement on these aspects, Angeli et al. (2016, p.49) attempted to unify existing definitions. The authors define CT as "a thinking process that uses the elements of abstraction, generalisation, decomposition, algorithmic thinking and debugging (error detection and correction)". There is also a lack of consensus on other issues, such as its scope or nature (González et al., 2018; Rich & Langton, 2016). This continues to highlight the need to further delimit the term (Bocconi et al., 2016) in order for it to be fully and effectively included in education.

In most countries, the integration of CT takes place mainly at the secondary education stage (Haseski & Ilic, 2019). However, it is necessary to include it from elementary education levels in the same way as other basic skills such as numeracy or reading (Zapata-Ros, 2015). CT can enable the development of skills such as creativity, problem solving or collaborative skills (Arranz & Pérez, 2017). Including it in primary school would also help to alleviate gender differences in CT development (Ketelhut et al., 2019; Shute et al., 2017). However, for this inclusion to be truly effective, a number of methodological and pedagogical criteria must be established. There is a clear need for further studies in this direction, as they are still scarce (Haseski & Ilic, 2019).

Another aspect that also requires further study is the evaluation of CT (Bocconi et al., 2016; Cutumisu et al., 2019, Lockwood & Mooney, 2017; Román-González et al., 2017). Existing tools and methods cover only certain aspects, focusing more on computational concepts than on practices or perspectives. The existence of multiple definitions of CT has generated a wide variety of assessment methods that lack sufficient validation (Cutumisu et al., 2019; Shute et al., 2017).

Teachers play a key role in the inclusion of CT in schools (Yadav et al., 2017). Teacher qualifications are considered a major factor for educational quality and an essential driver for effectively addressing educational change. The introduction of CT to education policy is creating a strong demand for teacher training, as most teachers do not learn about CT in their initial training (Bocconi et al., 2016; Bustillo, 2015; Ling et al., 2018; Yadav et al., 2017). Given the shortage of teachers qualified to teach this type of thinking and effectively use tools to foster its development (Ling et al., 2018), more studies focusing on this group (Haseski & Ilic, 2019) are needed to design evidence-based training plans.

Several researchers have addressed some of these issues in systematic reviews or literature reviews conducted more frequently since 2014. Works such as Kalelioğlu et al. (2016) and Cometa et al. (2021) provide an overview of the status of CT. Shute et al. (2017) analyse different aspects related to this thinking (characteristics and components, interventions to develop it, evaluation and existing theoretical frameworks and models). Others focus on specific dimensions. Pollak and Ebner

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(2019) investigate the integration of CT, and Palts and Pedaste (2020) discuss the dimensions of CT thinking skills and how they can be combined in a new model to develop CT thinking. Cutumisu et al. (2019), Alves et al. (2019) and Tang et al. (2020) discuss, from different perspectives, the assessment of CT. Ioannou and Makridou (2018), Uslu et al. (2022) and Xia and Zhong (2018) focus on robotics, while Lye and Koh (2014), Popat and Starkey (2018) and Zhang and Nouri (2019) analyse different aspects related to coding. Other studies, such as García-Tudela and Marín-Marín (2023), are more specific and analyse the uses and achievements of Arduino. Barcelos et al. (2019) and Chan et al. (2023) address the development of mathematical learning through CT activities. Menon et al. (2019) investigate the use of escape board games to develop and assess CT.

Although the authors of the aforementioned systematic reviews address some of the issues surrounding CT, it remains unclear whether there are methods, specific strategies or tools that can be used to successfully incorporate it from the primary education stage onwards. The search for these answers, which is the subject of this new systematic review, contributes to the subsequent identification of the keys to defining what initial teacher education in universities should be like. We believe that school practice influences and provides valuable information for the design of curricula in faculties of education.

In this context, this systematic review seeks answers to the following research questions:

What are the main learning strategies, inclusion principles and tools used in the implementation of CT at the primary education stage (6-12 years old)?

What are the main characteristics of the design of initial and in-service training experiences for primary school teachers in CT?

METHOD

In this study, evidence is gathered on the current situation regarding teacher training and the implementation of CT in primary education. The general objective is to draw conclusions about the teaching-learning process of CT in primary education that can be considered in university teacher training.

The research design follows the process established by Kitchenham and Charters (2007) for conducting systematic reviews and the recommendations offered by Sánchez-Meca (2022). The guidance and checklist of the PRISMA 2020 Declaration (Page et al., 2021) are also accounted for. Annex I shows which suggestions from this checklist have been met, which have not been met, and which are not appropriate to check, as this is not a meta-analysis.

Selection criteria

The selection of studies was based on the criteria set out in Table 1.

In 2006, Wing published his article titled Computational Thinking, which, together with international education policies and the impetus of the technology industry, led to an increase in the popularity of the term and interest in its study and inclusion in the classroom. This milestone justifies the criterion that eligible studies were published between 2006 and 14 March 2023, the day in which the search was conducted.

Table 1
Inclusion criteria

Inclusion criteria	Description
Type of study	Empirical studies
Place of publication	Peer-reviewed journals in any field of knowledge
Language	Spanish or English
Date of publication	Between 2006 and 14 March 2023
Content	Related to the objective and research questions

Source: own elaboration.

Search strategies

The Scopus and Web of Science (WOS) databases were used to search for articles, following the unregistered protocol set out in Table 2.

Table 2
Search protocol

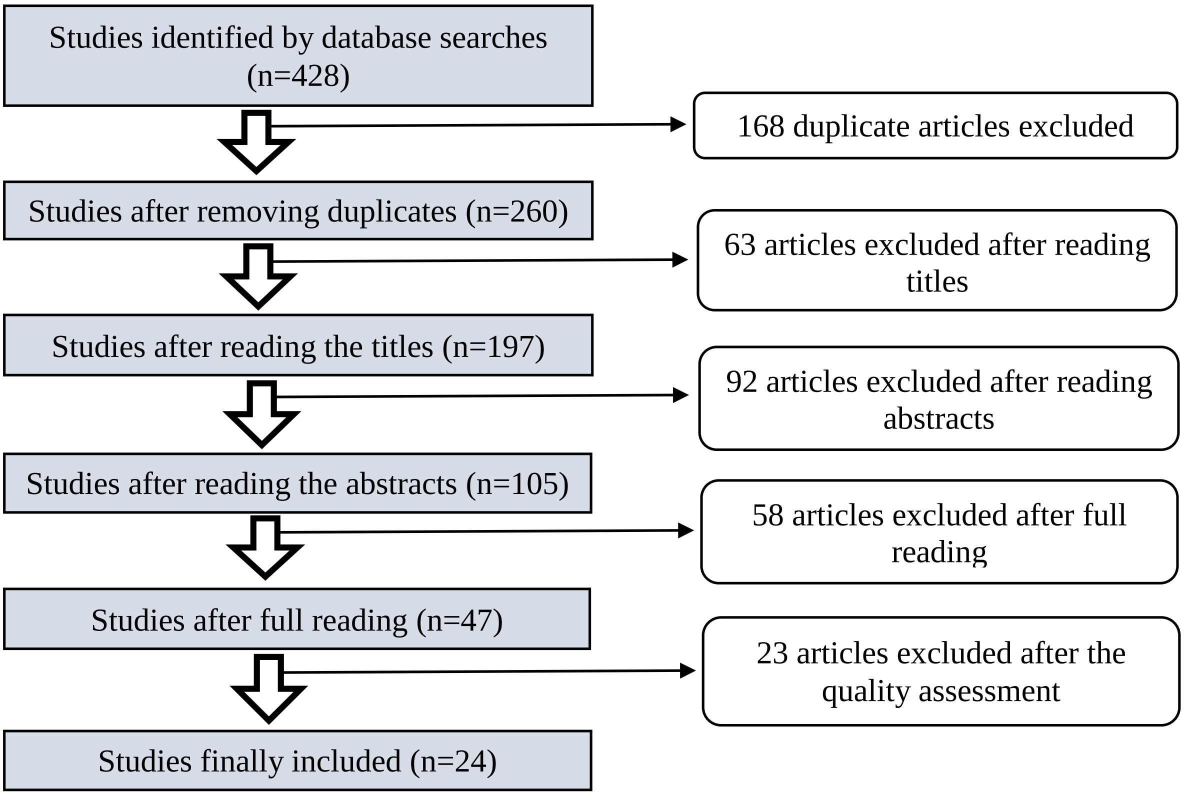
Database	Search protocol
Scopus	Search string (article title): "Computational thinking" AND "Elementary" OR "Primary" OR "K-12" OR "Teacher training" OR "education*". Limited year of publication: from 2006 to 14 March 2023 Limited language: English or Spanish. Limited document type: articles. Limited resource type: magazine. Search conducted on 14 March 2023.
Web Of Science: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (AyHCI), Emerging Sources Citation Index (ESCI)	Search string: (TI=("computational thinking")) AND TI=("elementary" OR "K-12" OR "primary" OR "teacher training" OR "education*"). Limited year of publication: from 2006 until 14 March 2023 Limited language: English or Spanish. Limited document type: articles. Search conducted on 14 March 2023.

Source: own elaboration.

Procedure for the selection of studies

After an initial search in Scopus and WOS, 231 and 197 articles were obtained, respectively. A total of 168 duplicate articles were eliminated. Subsequently, the titles were read, and 63 articles were eliminated because they were not clearly related to the research objectives. Next, the abstracts were read, and 92 articles were eliminated. After a thorough reading, the selection was reduced to 47 studies. Finally, the quality of these articles was assessed (the procedure is detailed in the following section), and 24 articles were selected, as shown in Figure 1. This whole process was carried out by the researcher who is the first author of this article.

Figure 1
Procedure for article selection



Assessment of the quality of studies

The Critical Appraisal Skill Programme (CASP) checklist[1] was used to assess the quality of the articles. This tool, developed by the Oxford Centre for Triple Value Healthcare, allows the critical appraisal of the reliability and relevance of the results obtained in the different studies, regardless of the area of knowledge from which they originate. It provides ten questions that are accompanied by a series of indications for answering them correctly. With the application of the CASP checklist, the aim is to eliminate the risk of bias to guarantee the credibility and generalizability of the results obtained.

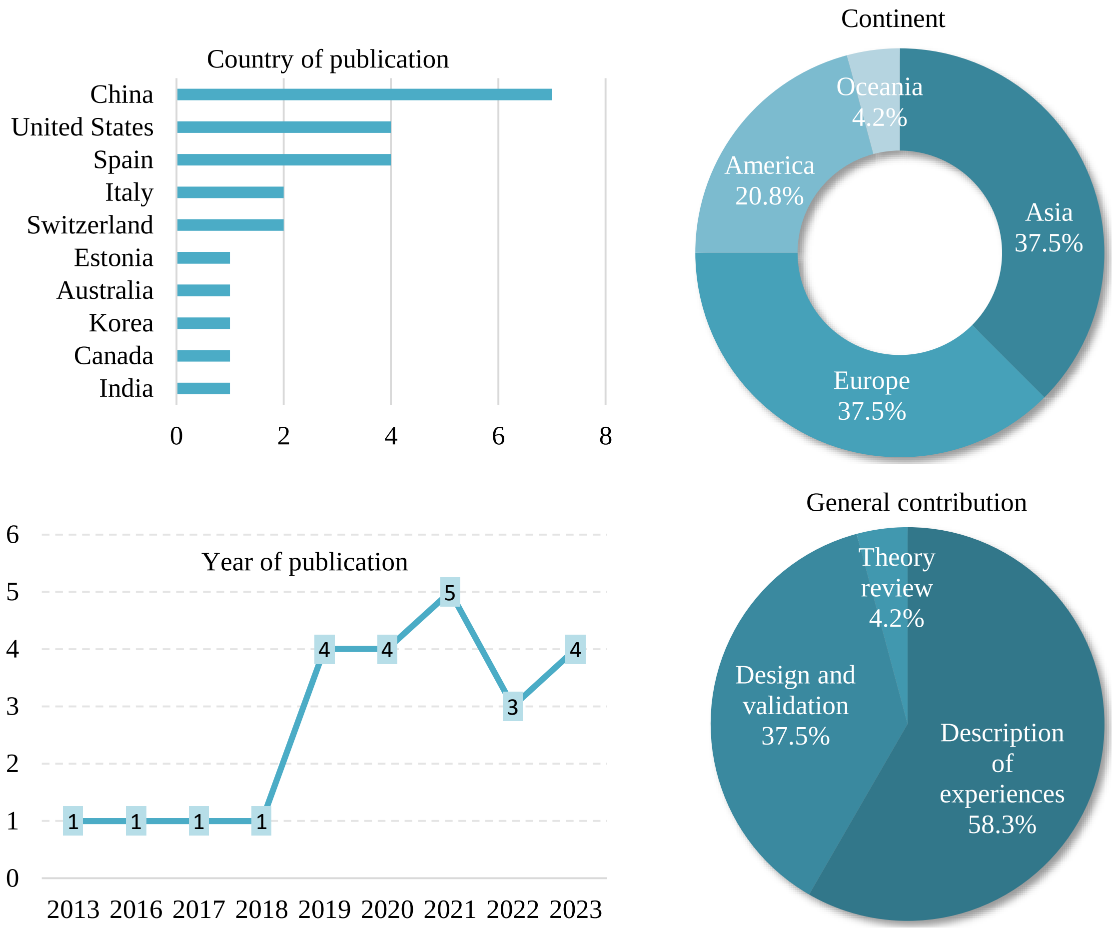
To assess the different types of studies, an adaptation of the CASP checklist including nine questions was created. The quality of the studies was assessed independently by two investigators, as shown in Annex II. Papers were labelled high quality (≥70%), moderate quality (69-40%) or low quality (<40%). Only articles of high and moderate quality (n=24) were included. Excluded articles are shown in Annex III.

RESULTS

Following the procedure developed in the previous section, a total of 24 articles were selected. Analysing their general characteristics revealed that most of the articles were published from 2019 onwards, with a concentration in 2021. Most of the studies took place in China, followed by the United States and Spain. The continents of Asia and Europe accounted for most of the selected articles. Analysing the general contributions of the research, 58.3% were based on the description of CT experiences with students or teachers and future primary school teachers, and 37.5% were based on the design and validation of CT models, programmes, resources or evaluation instruments. In terms of research design, most of the studies used quantitative or mixed methods. Experiments with an experimental and control group and the use of pretest and posttest predominated.

Figure 2

Distribution of studies by country, continent, year of publication and overall contributions



In relation to the research questions and the objectives of the review, most of the articles were related to the implementation and evaluation of experiences with CT among primary school students. Only 6 of the 24 articles dealt with the training of in-service or future teachers. The most relevant results are developed below:

Implementing computational thinking in primary education

Most studies focused on students in the third to sixth grades of primary school (Basu et al., 2021; Chevalier et al., 2020; Chiazzese et al., 2019; El-Hamamsy et al., 2022; Freina et al, 2019; Hooshyar et al., 2021; Huang et al.,2023; Jiang & Li, 2021; Liu et al., 2023; Noh & Lee, 2019; Sáez & Cózar, 2017; Sengupta et al., 2013; Shen et al., 2020; Tran, 2019; Wei et al., 2021). Only four studies (Caballero-González & García-Valcárcel, 2020; Del Olmo et al., 2020; El-Hamamsy et al., 2022; Yadav & Chakraborty, 2023) addressed initial levels.

Regarding the tools used, most studies employed robotics (Caballero-González & García-Valcárcel, 2020; Chevalier et al., 2020; Chiazzese et al., 2019; Liu et al, 2023; Noh & Lee, 2019; Shen et al., 2020) and/or computer programming (Basu et al., 2021; Freina et al., 2019; Jiang & Li, 2021; Sáez & Cózar, 2017; Sengupta et al., 2013; Tran, 2019; Wei et al., 2021). Most did so through visual programming environments, such as Scratch (Basu et al., 2021; Chevalier et al., 2020; Freina et al., 2019; Jiang & Li, 2021; Sáez & Cózar, 2017; Sengupta et al., 2013; Wei et al., 2021), App Inventor (Basu et al., 2021) or Blockly (Tran, 2019).

Only two papers (Basu et al., 2021; Del Olmo et al., 2020) addressed CT without using technological devices. Other studies made use of computer games (Hooshyar et al., 2021) or board games enriched with augmented reality (Huang et al., 2023). Finally, apps were also used, such as Lightbot, Code Hour, Q Space App, Preschool and kindergarten app and Luca's educational patterns game app (Yadav & Chakraborty, 2023).

With regard to the learning strategies followed to develop CT in primary school, learning by doing stands out (Chiazzese et al., 2019; Freina et al., 2019; Hooshyar et al., 2021; Jiang & Li, 2021; Liu et al., 2023; Sáez & Cózar, 2017; Shen et al, 2020; Yadav & Chakraborty, 2023), followed by collaborative work (Caballero-González & García-Valcárcel, 2020; Chevalier et al., 2020; Chiazzese et al., 2019; Freina et al., 2019; Jaipal-Jamani & Angeli, 2016; Jiang & Li, 2021; Liu et al, 2023; Noh & Lee, 2019; Tran, 2019; Wei et al., 2021), scaffolding (Chevalier et al., 2020; Freina et al., 2019; Jaipal-Jamani & Angeli, 2016; Sengupta et al., 2013; Yadav & Chakraborty, 2023), and solving problems or challenges (Basu et al., 2021; Caballero-González & García-Valcárcel, 2020; Chevalier et al., 2020; Chiazzese et al., 2019; Freina et al., 2019; Jiang & Li, 2021; Liu et al., 2023; Shen et al., 2020; Yadav & Chakraborty, 2023).

Other studies revealed some principles to consider for CT inclusion to be truly effective: taking students' prior skills into account (Chiazzese et al., 2019; Huang et al.,2023; Liu et al., 2023; Noh & Lee, 2019; Sengupta et al, 2013); using varied environments, tools and activities to respond to the diversity of learners (Sengupta et al., 2013; Tran, 2019); and developing CT from the lowest levels (Caballero-González & García-Valcárcel, 2020; El-Hamamsy et al., 2022; Del Olmo et al., 2020; Tran, 2019; Yadav & Chakraborty, 2023). Given the near nonexistence of methodological and pedagogical principles for teaching CT in primary school, some authors designed their own models and approaches (Chevalier et al., 2020; Liu et al., 2023; Sengupta et al., 2013).

Several studies presented examples of the inclusion of CT in curricular areas, especially in STEM areas such as computer science, science and mathematics (Chiazzese et al., 2019; Sengupta et al., 2013; Tran, 2019; Yadav & Chakraborty, 2023) but also others discussed this in areas such as art education (Sáez & Cózar, 2017). The remaining studies created unique programmes without integrating them into specific curricular areas.

The most commonly used assessment instrument was the selection and adaptation of Bebras tests (Chiazzese et al., 2019; Del Olmo et al., 2020; Huang et al., 2023; Noh & Lee, 2019; Yadav & Chakraborty, 2023). Some authors (Hooshyar et al., 2021; Jiang

& Li, 2021; Liu et al., 2023) used or adapted validated instruments, such as the CT test (CCT) by Román-González et al. (2015), the CT scale (CTS) by Korkmaz et al. (2017) or Dr. Scratch by Moreno-León et al. (2015). Other authors created their own assessment instruments developed specifically for the experience conducted (Basu et al., 2021; El-Hamamsy et al., 2022; Shen et al., 2020; Tran, 2019). Authors such as El-Hamamsy et al. (2022) highlighted the importance of combining several CT tests to adequately assess students' computational competences.

Teacher training in computational thinking

Effective inclusion of CT in primary classrooms requires teachers to possess a range of pedagogical skills and knowledge. However, the reality is that most teachers have no prior CT training or have misconceptions about CT (Chalmers, 2018; Freina et al., 2019; Jaipal-Jamani & Angeli, 2016). However, we found studies showing that teachers experience an increase in their computer skills and confidence in including CT in the classroom after participating in training experiences (Chalmers, 2018; Jaipal-Jamani & Angeli, 2016; Kong & Lai, 2022; Molina-Ayuso et al., 2022; Rich et al., 2021).

Most of the teacher education experiences reviewed were aimed at in-service teachers (Chalmers, 2018; Kong et al., 2023; Kong & Lai, 2022; Rich et al., 2021). Only two studies (Jaipal-Jamani & Angeli, 2016; Molina-Ayuso et al., 2022) targeted prospective primary school teachers. The duration of these training experiences was quite variable, with some experiences lasting less than three months (Chalmers, 2018; Jaipal-Jamani & Angeli, 2016) and others lasting more than eight months (Kong et al., 2023; Kong & Lai, 2022; Rich et al., 2021).

Regarding the content of these learning experiences, some papers addressed computer programming (Kong et al., 2023; Kong & Lai, 2022; Molina-Ayuso et al., 2022; Rich et al., 2021) or robotics (Chalmers, 2018; Jaipal-Jamani & Angeli, 2016). Only the study by Kong and Lai (2022) considered the use of disconnected activities. Among the works which addressed computer programming, those describing the use of Scratch or Scratch Jr (Kong et al., 2023; Kong & Lai, 2022; Molina-Ayuso et al., 2022; Rich et al., 2021) stand out, although other resources, such as App Inventor (Kong et al., 2023; Kong & Lai, 2022) are also used. Robotics is addressed with Lego WeDo kits (Chalmers, 2018; Jaipal-Jamani & Angeli, 2016).

Analysing the structure of the courses reveals that most of them opt for an initial instruction phase and a practice or knowledge implementation phase (Jaipal-Jamani & Angeli, 2016; Kong et al., 2023; Kong & Lai, 2022; Molina-Ayuso et al., 2022; Rich et al., 2021). The most commonly employed strategies are collaborative work (Jaipal-Jamani & Angeli, 2016; Kong et al., 2023), modelling (Kong & Lai, 2022; Rich et al., 2021) and scaffolding (Jaipal-Jamani & Angeli, 2016; Kong et al., 2023).

Finally, the evaluation of training experiences was very diverse and was carried out using a variety of tests created specifically for the experience or adapted from existing ones. All studies assessed both teachers' knowledge acquisition and their reflections on the experience. Studies such as Chalmers (2018) and Kong and Lai (2022) are relevant because they provided information on the challenges teachers face.

Tables 3 and 4 show a synthesis of the above results.

Table 3
Synthesis of results. Implementation of computational thinking in primary education

Authors	Year	Country	Course	Area	Teaching strategies	Resources	Data collection instruments
Sengupta et al	2013	United States	6th	Science	Constructivism Scaffolding Modelling	NetLogo	CT-specific tests
Sáez y Cózar	2017	Spain	6th	Arts education	Play-based learning	Scratch Picoboard Raspberry Pi	Specific CT questionnaire Interview
Chiazzese et al.	2019	Italy	3rd and 4th	Computing	Instruction and learning by doing (projects) Collaborative learning	Lego WeDo 2.0	Tests Adapted Bebras Opinion questionnaire
Freina et al	2019	Italy	5th	Integrated into the school curriculum	Instruction and learning by doing (projects) Collaborative learning Scaffolding	Scratch	Interview Remarks Student diaries Opinion questionnaire Scratch Test Sociogram
Noh and Lee	2019	Korea	5th and 6th	Specific course	Specific instructional design Creative problem-solving model Collaborative learning	Entry Robot hamster	Tests Adapted Bebras Creative thinking test
Tran	2019	United States	3th	Specific programme integrated into the school curriculum	Constructivism Collaborative learning	Code.org Cs unplugged	Specific CT test Interview
Caballero-González and García-Valcárcel	2020	Spain	1st	Integrated into the school curriculum	Collaborative learning Learning by doing (challenges)	Beebot	Adapted rubric

Authors	Year	Country	Course	Area	Teaching strategies	Resources	Data collection instruments
Chevalier et al	2020	Switzerland	4th	Not specified	Creative problem-solving model Collaborative learning	Thymio Robot	Remarks
Del Olmo et al.	2020	Spain	2nd	Not specified	Mixed approach (CT unplugged and CT plugged in)	Unplugged tasks Code.org	Tests Adapted Bebras Adapted motivation test
Shen et al.	2020	United States	5th	Specific curriculum	Instruction and learning by doing (projects)	NAO humanoid robot	Specific CT test
Basu et al.	2021	China	4th, 5th and 6th	Troubleshooting	Troubleshooting	Scratch App inventor	Specific CT test Interview
Hooshyar et al.	2021	Estonia	5th	Not specified	Learning by doing	Autothinking	Adapted CT test Adapted attitude questionnaire
Jiang and Li	2021	China	5th	Specific compulsory course	Instruction and learning by doing (projects) Collaborative learning	Scratch	CT Test
Wei et al	2021	China	4th	Specific course	Collaborative learning	Scratch	Survey Interview Dr. Scratch
El-Hammamsy et al	2022	Switzerland	3rd and 4th	Not specified	Not applicable (validation of an assessment tool)	CT disconnected	Specific CT test
Huang et al	2023	China	3rd	Not specified	Play-based learning	Scratch block-based board game Augmented Reality	Specific CT test
Liu et al.	2023	China	5th	Not specified	Reverse engineering pedagogy Instruction and learning by doing (projects) Collaborative learning	UKit Explore Robotics	Adapted CT test

Authors	Year	Country	Course	Area	Teaching strategies	Resources	Data collection instruments
Yadav and Chakraborty	2023	India	2nd	Integrated into the school curriculum	Instruction and learning by doing Scaffolding	Apps: The Lightbot: Code Hour; Kid's Educational Games: Preschool and Kindergarten; Lucas' Educative Patterns Game; Q space	Tests Adapted Bebras

Source: Own elaboration.

Table 4
Synthesis of results. Teacher training in computational thinking

Authors	Year	Country	Type of training	Experience	Duration	Teaching strategies	Resources	Data collection instruments
Jaipal-Jamani and Angeli	2016	Canada	Initial	Scientific methods course	12 weeks	Instruction and learning by doing (homework) Collaborative learning Scaffolding	Lego WeDo	Tailored interest questionnaire Adapted self-efficacy questionnaire CT Questionnaire Tasks
Chalmers	2018	Australia	Permanent	Experience of integrating CT in classrooms	6 weeks	Learning by doing	Lego WeDo 2.0	Opinion questionnaire Semistructured interviews Reflection journal
Rich et al	2021	United States	Permanent	Specific programme to train teachers in CT	1 year	Learning by doing (challenges) Modelling Sharing experiences and projects Debates	Scratch Scratch Jr	CT Survey Opinion polls
Kong and Lai	2022	China	Permanent	Specific curriculum	48 hours of training	Instruction and learning by doing	Scratch App inventor	Opinion poll

Authors	Year	Country	Type of training	Experience	Duration	Teaching strategies	Resources	Data collection instruments
Molina-Ayuso et al	2022	Spain	Initial	Didactics of numerical operations and measurement	5 days	Instruction and learning by doing (challenges)	Scratch	Tests of adapted Bebras Adapted CT test Opinion poll
Kong et al	2023	China	Permanent	Scalable teacher development programme	1 school year	Collaborative work Learning by doing Mentoring	Scratch App Inventor	PC-specific test Transcripts of meetings Opinion poll

Source: own elaboration.

DISCUSSION

In this section, we present a general interpretation of the results in the context of other studies and discuss their implications for educational practice and future research. In addition, we show in the final part of this section the most substantial limitations we identified from this systematic review.

First, we contrasted our results with those obtained in other research on the implementation of CT in primary education (first research question).

Although education systems in many countries have modified their curricula to respond to the need for the efficient inclusion of CT in primary classrooms, we have found that there are very few studies that focus on the first two years of primary school, which undermines the desirability of starting CT development early. This also makes it difficult to recommend a gradual shift from offline to technology-based activities (Brackmann et al., 2017; Serrano & Ortuño, 2021).

Visual block programming and robotics were the most commonly used strategies or tools in the reviewed studies, coinciding with the conclusions obtained in two meta-analyses (Merino-Armero et al., 2021; Sun et al., 2021), which indicated that robot programming is the most efficient strategy for CT development in primary education.

The use of disconnected activities was fairly limited in the selected studies. This contrasts with the advantages, especially in primary school (Serrano & Ortuño, 2021), that this strategy has according to several previous studies (Huang & Looi, 2020; Weigend et al., 2019). In one meta-analysis (Li et al., 2022), the authors also concluded that both unplugged activities and scheduling exercises are useful for CT development among students. According to this study, the effects of programming are somewhat better than those provided by disconnected activities and are enhanced when working in an interdisciplinary way and not only within specific subjects, which is far from the results of our research.

In relation to the teaching strategies employed, we concluded that there are a number of strategies that are suitable for use, including instructional and learning-by-doing strategies, scaffolding, collaborative work and problem or challenge solving, thus largely agreeing with previous work (Park & Park, 2018; Kale et al., 2018; Voogt et al., 2015). However, game-based learning was reported in some previous studies (Kaleliïoğlu et al., 2016) as one of the most commonly used strategies in CT development experiences, a conclusion that does not coincide with the results obtained in our review.

Some authors analysed how to assess CT development, showing that there is a great gap in terms of valid assessment tools and strategies (Alves et al., 2019). Although there are instruments for assessing CT development in primary education (Bebras, CCT Test, CTS Scale, Opinion polls, Dr. Scratch, etc.), we find that they are not useful for verifying the real and complete development of CT, as they focus more on programming skills than on analysing the development of CT components. In the absence of effective approaches to assess CT in primary school, we propose the combination of multiple assessments to cover all dimensions of CT. This issue requires further research, as already noted in previous studies (Cutumisu et al., 2019; Lockwood & Mooney, 2017; Román-González et al., 2017).

Second, we discuss the characteristics of CT teacher education at the primary school level (second research question).

According to the results obtained, we note the scarcity of studies that rigorously evaluate training experiences, especially in initial teacher training, coinciding with the results of other research (Bocconi et al., 2016; Bustillo, 2015; Ling et al., 2018; Yadav et al., 2017). This is most likely because there is still no proliferation of teacher training plans for CTdevelopment, which is still a pending goal, as pointed out by Haseski and Ilic (2019). Educational institutions should take the lead in teacher training, as they are the best places for teachers to reflect on their previous beliefs about CT, to learn about key concepts and, most importantly, to adopt the most appropriate pedagogical approaches (González et al., 2018; Yadav et al., 2017).

Introducing CT concepts in the initial training of teachers is a key strategy for achieving this goal since it is at that time that they are generally most willing to understand the relevance of CT within their own discipline (Butler & Leahy, 2021; Yadav et al., 2014). In any case, beyond specific training actions, the implementation and evaluation—in different contexts—of training proposals is needed, and fortunately, such efforts are beginning to emerge and can be consulted in different works (Esteve-Mon et al., 2019; Kotsopoulos et al., 2017; Serrano & Ortuño, 2021; Tsai et al., 2021; Voon et al., 2023).

In addition to the need to design training models that operationalize CT development with specific strategies, importantly, there are generic pedagogical models that can be the basis for designing specific models. Some authors (Kale et al., 2018; Yadav et al., 2017) consider the TPACK (technology, pedagogy, and content knowledge) model, promoted by Mishra and Koehler (2006), to be useful for teaching CT in initial teacher education. This model includes preservice teachers learning about the effective integration of technology within the context of subject matter and pedagogy; similarly, teachers need to develop CT knowledge within the context of their content knowledge and pedagogical knowledge.

The study by Kong et al. (2020) presented a (primary) teacher development programme to develop CT competences in relation to programming and the TPACK model. The researchers identified concerns among teachers about programming due to the lack of efficient and pedagogically rich training support. The authors proposed a pedagogy for playing, thinking and coding for the development of computer skills with programming in primary schools.

Despite the emphasis on CT as a mental tool that extends beyond computer-based environments, most current teacher professional development efforts have focused on exposing teachers to programming environments, consistent with the findings of our review. Thus, teachers should be engaged to think about how CT can be integrated into authentic learning situations in other content areas. The training programme developed by Yadav et al. (2018) highlights this idea.

The pedagogical knowledge training of primary school teachers is, in general, solid. However, this needs to be complemented by CT-specific pedagogical practices and content, such as modelling a problem, thinking about or solving a problem iteratively and incrementally, or explaining a solution to a problem in a series of steps (Carlborg et al., 2019).

Furthermore, we found that in-service teachers carry out training that varies in duration and is very focused on technical aspects such as computer programming and robotics, leaving in the background the use of unplugged activities and issues related to didactic strategies, precisely those aspects that have a high impact on learning in promoting CT among future students, as mentioned above.

In summary, we conclude that – most likely – many teachers are trying to integrate CT into their classrooms without having the necessary competences, especially those that should be developed during initial teacher training. Such training should be based on the principles of educational technology, involve teachers in the task of determining how to integrate CT into learning situations in an interdisciplinary way, be complemented by pedagogical practices and CT content, go beyond teaching programming, and incorporate offline activities as a preliminary step in robot programming. The effectiveness of these training programmes requires improved approaches to CT development assessment beforehand.

Third, we refer to the main limitations of the research. The remaining limitations, which we consider minor, can be found in the PRISMA 2020 checklist (Annex I).

This systematic review analyses the studies collected by Scopus and WOS. With this inclusion criterion, we deliberately discarded other types of publications that could be equally valuable. This decision was made because previous systematic reviews did account for studies published in journals indexed in databases such as ERIH Plus. It would be valuable to consider unpublished "grey literature" on the topic to counteract the problem of publication bias. However, we argue that this limitation does not detract from the validity of the conclusions obtained. Selecting studies published in high-impact journals is a useful, necessary and accepted filter among the scientific community.

Although in the first task of article selection (reading article titles) we discarded those studies that were clearly not related to the research, we consider that in order to avoid bias and errors, it would be more convenient to analyse the abstracts as well. Another aspect to improve in this part in future studies is that the selection of studies should be done by more than one reviewer and in an independent manner. This recommendation was partially followed during the assessment of the quality of the papers with the CASP checklist, in which the two researchers who signed this article participated. In relation to this instrument, we consider that its utility is questionable for two reasons: because it does not distinguish studies according to the type of research design of each study and because of its limited application in studies in the social sciences. We recommend exploring and selecting other checklists or scales available on the Equator Network website[2].

NOTES

[1.] Web de CASP: https://casp-uk.net/
[2.] Sitio web Equator Network: https://www.equator-network.org/

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Conflict of interest

The authors declare that there are no relationships or activities that may have influenced the conduct of this systematic review.

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ANNEX I. Prism checklist

Supplementary material to this article can be found in its electronic version at: https://joseluisserrano.net/annex-I-PRISMA-RIED-EN.pdf

ANNEX II. Results obtained in the evaluation of the quality of the articles

To assess the quality of the studies, an adaptation of the CASP checklist has been used. The questions, as numbered in the table, are as follows:

1. Is the focus of the research topic clearly defined?
2. Is the information sought out by the authors adequate?
3. Have the authors identified all the important confounding factors?
4. Was the follow-up of the topics comprehensive enough?
5. Are the results linked to the objectives?
6. Are the results accurate?
7. Are the results applicable to other types of populations?
8. Are the results of this study consistent with other available evidence?
9. Are the implications of this study valid for practice?

Each question was scored with "Yes = 1", "No = 0" and "UN = Unclear". High (≥70%) and moderate (69-40%) quality studies included in this review are highlighted in Table 5.

Table 5
Results obtained in the quality assessment of the articles

Study	Researcher	1	2	3	4	5	6	7	8	9	%	Average %
Ángel-Díaz et al. (2020)	A	1	UN	UN	UN	1	0	0	0	UN	22.2	27.8
	B	1	1	0	UN	1	0	0	UN	UN	33.3	
Basu et al. (2021)	A	1	1	1	1	1	1	UN	0	UN	66.7	66.7
	B	1	1	1	1	1	1	0	0	UN	66.7	
Caballero-González & García-Valcárcel (2020)	A	1	1	0	UN	1	1	0	1	1	66.7	55.6
	B	1	UN	0	0	1	1	0	1	UN	44.4	
Chalmers (2018)	A	1	UN	0	0	0	1	0	1	1	44.4	50.0
	B	1	1	UN	0	0	1	0	1	1	55.6	
Chen et al. (2017)	A	1	UN	0	UN	1	1	UN	UN	UN	33.3	33.3
	B	1	0	0	UN	1	1	UN	0	UN	33.3	
Chevalier et al. (2020)	A	1	1	0	0	1	1	0	1	1	66.7	55.6
	B	1	1	0	0	1	UN	0	1	UN	44.4	
Chevalier et al. (2022)	A	1	UN	0	UN	1	1	0	UN	UN	33.3	27.8
	B	1	0	0	0	1	UN	0	0	UN	22.2	
Chiazzese et al. (2018)	A	1	UN	0	0	1	UN	0	UN	0	22.2	27.8
	B	1	1	0	0	1	0	0	0	0	33.3	
Chiazzese et al. (2019)	A	UN	1	0	1	1	1	1	UN	1	66.7	66.7
	B	1	1	0	1	1	1	UN	UN	1	66.7	
Connolly et al. (2021)	A	1	0	0	0	1	UN	0	UN	UN	22.2	22.2
	B	1	UN	0	0	1	UN	0	0	0	22.2	
Del Olmo-Muñoz et al. (2020)	A	1	1	0	UN	1	1	1	1	1	77.8	77.8
	B	1	1	0	0	1	1	1	1	1	77.8	
El-Hamamsy et al. (2021)	A	1	UN	0	0	UN	1	UN	UN	UN	22.2	22.2
	B	1	0	0	0	UN	1	0	0	UN	22.2	
El-Hamamsy et al. (2022)	A	1	1	UN	1	1	1	UN	1	1	77.8	72.3
	B	1	1	1	1	UN	UN	0	1	1	66.7	

Study	Researcher	1	2	3	4	5	6	7	8	9	%	Average %
Freaina et al. (2019)	A	1	1	0	0	1	1	0	0	1	55.6	50.0
	B	1	1	0	0	UN	1	0	0	1	44.4	
Gamito et al. (2022)	A	1	UN	0	UN	1	0	0	1	UN	33.3	33.3
	B	1	UN	0	0	1	0	0	1	UN	33.3	
Gane et al. (2021)	A	1	1	0	0	1	UN	0	UN	UN	33.3	27.8
	B	1	UN	0	0	1	0	0	0	UN	22.2	
Gao & Hew (2022)	A	1	1	UN	UN	1	UN	0	0	UN	33.3	33.3
	B	1	1	UN	0	1	UN	0	0	0	33.3	
Hooshyar et al. (2021)	A	1	1	1	UN	1	1	UN	1	1	77.8	77.8
	B	1	1	UN	UN	1	1	1	1	1	77.8	
Hsu et al. (2022)	A	1	UN	0	UN	1	1	0	UN	UN	33.3	33.3
	B	1	0	0	0	1	1	0	0	UN	33.3	
Huang et al. (2023)	A	1	1	0	0	1	1	0	1	UN	55.6	50.0
	B	1	1	0	0	UN	1	0	1	UN	44.4	
Jaipal-Jamani & Angeli (2017)	A	1	UN	0	UN	1	1	0	1	1	55.6	50.0
	B	1	1	0	UN	UN	1	0	1	UN	44.4	
Jiang & Li (2021)	A	1	UN	0	UN	1	1	0	1	UN	55.6	61.2
	B	1	1	0	UN	1	1	0	1	1	66.7	
Kastner-Hauler et al. (2022)	A	1	UN	0	UN	1	UN	UN	0	UN	22.2	22.2
	B	UN	1	0	UN	1	0	UN	0	UN	22.2	
Kim & Kim (2016)	A	1	UN	0	0	1	UN	0	0	UN	22.2	22.2
	B	1	UN	0	0	1	0	0	0	UN	22.2	
Kong et al. (2023)	A	1	1	0	UN	1	1	0	1	UN	55.6	55.6
	B	1	1	0	UN	1	1	0	1	UN	55.6	
Kong & Lai (2021)	A	1	UN	0	UN	1	1	UN	UN	UN	33.3	33.3
	B	1	UN	0	0	1	1	0	UN	UN	33.3	
Kong & Lai (2022)	A	1	1	0	1	1	1	0	UN	1	66.7	55.6
	B	1	UN	0	1	1	UN	0	0	1	44.4	

Study	Researcher	1	2	3	4	5	6	7	8	9	%	Average %
Li et al. (2021)	A	1	1	0	0	1	UN	0	0	UN	33.3	33.3
	B	1	1	0	0	1	UN	0	0	UN	33.3	
Liu et al. (2023)	A	1	UN	1	UN	1	1	0	1	UN	55.6	61.2
	B	1	1	1	0	1	1	0	1	UN	66.7	
Matere et al. (2021)	A	1	UN	0	UN	1	1	0	UN	UN	33.3	38.9
	B	1	0	0	1	1	1	0	0	UN	44.4	
Molina-Ayuso et al. (2022)	A	1	1	1	1	1	1	UN	1	1	88.9	83.4
	B	1	UN	1	1	1	UN	1	1	1	77.8	
Noh & Lee (2020)	A	1	1	0	1	1	1	1	1	1	88.9	88.9
	B	1	1	0	1	1	1	1	1	1	88.9	
Pewkam & Chamrat (2022)	A	1	UN	0	UN	1	UN	0	1	UN	33.3	27.8
	B	1	0	0	0	UN	UN	0	1	UN	22.2	
Rich et al. (2020)	A	1	1	0	1	UN	0	UN	0	UN	33.3	22.2
	B	1	UN	0	UN	0	0	UN	0	UN	11.1	
Rich et al. (2021)	A	1	1	0	UN	1	1	0	1	UN	55.6	50.0
	B	1	UN	0	0	1	1	0	1	UN	44.4	
Rijke et al. (2018)	A	1	0	0	UN	1	UN	UN	1	UN	33.3	27.8
	B	UN	0	0	UN	1	0	0	1	UN	22.2	
Sáez & Cózar (2017)	A	1	1	1	UN	1	UN	UN	1	1	66.7	66.7
	B	1	1	1	UN	1	UN	UN	1	1	66.7	
Sengupta et al. (2013)	A	1	1	0	UN	1	1	0	1	UN	55.6	66.7
	B	1	1	0	1	1	1	UN	1	1	77.8	
Seo & Kim (2016)	A	1	UN	0	0	1	1	0	UN	UN	33.3	33.3
	B	1	UN	0	0	1	1	0	0	0	33.3	
Shen et al. (2022)	A	1	UN	UN	UN	1	1	0	1	1	55.6	61.2
	B	1	1	UN	UN	1	1	UN	1	1	66.7	
Silva et al. (2021)	A	1	0	0	0	1	UN	0	0	UN	22.2	22.2
	B	1	UN	0	0	1	UN	0	0	UN	22.2	

Study	Researcher	1	2	3	4	5	6	7	8	9	%	Average %
Tran (2019)	A	1	1	0	1	1	1	0	1	1	77.8	72.3
	B	1	1	0	1	1	UN	0	1	1	66.7	
Wang et al. (2022)	A	1	UN	0	UN	UN	1	0	0	UN	22.2	22.2
	B	1	0	0	0	0	1	0	0	UN	22.2	
Waterman et al. (2020)	A	1	UN	0	UN	1	0	0	UN	UN	22.2	22.2
	B	1	UN	0	UN	1	0	0	0	UN	22.2	
Wei et al. (2021)	A	1	1	0	UN	1	1	UN	1	1	66.7	61.2
	B	1	UN	0	0	1	1	0	1	1	55.6	
Yadav et al. (2018)	A	1	UN	0	UN	1	UN	0	UN	UN	22.2	27.8
	B	1	1	0	UN	1	0	0	UN	UN	33.3	
Yadav & Chakraborty (2023)	A	1	1	UN	UN	1	1	0	1	1	66.7	66.7
	B	1	UN	1	UN	1	1	0	1	1	66.7	

Source: own elaboration.

ANNEX III. References not included in the review

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