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Article

Review on pedagogical practices for computational thinking in teacher education: Characterizing an emerging field

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Abstract

As computational thinking (CT) enters school curricula, and research on teaching of CT emerges, the time has come to spotlight CT in teacher education (TE). To this end, we conducted a literature review on CT in TE for STEM subjects with particular focus on research into pre-service teachers' (PSTs) learning of pedagogical practices. We found 31 articles addressing CT in TE for STEM subjects between 2012 and 2023, applying qualitative, quantitative, and mixed methods, mainly with smaller sample sizes. Almost all describe teaching interventions with research on PSTs' CT skills or attitudes. Only five articles include research questions explicitly addressing pedagogical practices for learning to teach CT. However, 13 articles explicitly describe such pedagogical practices and another seven implicitly do so. The review shows that the practices for teaching CT is an under-researched area, and the field lacks a common language and systematic research approaches. However, we do find that TE has clear ambitions for teaching PSTs about pedagogical practices as well as CT skills and attitudes.

Keywords: Computational thinking, teacher education, literature review, second-order pedagogy, dual didactics

Introduction

In 2006 Wing re-introduced the notion of computational thinking (CT) as the way a computer scientist thinks and argued that CT is a fundamental skill for everyone (Wing, 2006). Since then, CT has been widely discussed – scientifically and politically (Haseski et al., 2018; Shute et al., 2017), and CT is implemented in many curricula worldwide. The main rationale for introducing CT is for fostering 21st century skills necessary to participate in the digital world (Bocconi et al., 2022). In addition, attracting students to computer sciences and fostering employability in the digital sector are common arguments (Bocconi et al., 2022) which may be linked to economic growth and future jobs (Bocconi et al., 2016b). The strategies for implementing CT in school differ between countries. In USA an important initiative is CSforALL, where CT has been introduced through the subject computer science. In Europe the implementation is diverse with three main strategies; either as a cross curricular theme, as part of a separate subject or within other subjects (Bocconi et al., 2022). The dominant trend in the Nordic countries is that CT emerges in subjects, however also cross curriculum initiatives are used (Bocconi et al., 2018; Tannert et al., 2022). Mathematics and science are the subjects with most CT integrations in teacher education (TE) (Ausiku & Mathee, 2021).

CT is a new and complex area of knowledge, and teachers are to a large degree not yet educated to teach it. The challenge of teaching CT in school is both a question of numbers of qualified teachers and development of content and pedagogy, which creates a demand for teacher training (Bocconi et al., 2022; Yadav et al., 2017). Cabrera (2019) found that in-service teachers hold many preconceptions about CT and teaching CT and considered such teaching to be difficult to implement in elementary and secondary schooling. Further Kafai and Proctor (2021) point out the need to research what knowledge of CT is necessary for future teachers.

Not enough is known about how pre-service teachers (PSTs) learn pedagogical practices for teaching CT. Delyser et al. (2018) and Ottenbreit-Leftwich et al. (2021) emphasise that the available research so far focuses on developing PSTs' CT content knowledge (Delyser et al., 2018; Ottenbreit-Leftwich et al., 2021). To contribute to the field, this review describes the research on CT education for PSTs with a particular focus on the development of their pedagogical practices. The research questions addressed are:

1) What characterizes research on CT in teacher education?

2) How does research on CT in teacher education address pedagogical practices for teaching CT in school?

In this review we focus on articles that *explicitly* address CT in TE. There are few published studies and most of them are relatively small, investigating single implementations of teaching modules, making it difficult to compare or extract generalized results. We therefore restrict our investigations to the studies' descriptions of implementation of CT in TE and aspects that need to be considered related to this, rather than extracting a best practice based on their findings.

Theoretical background

CT is related to computational problem solving and the creation of executable algorithms, and its operationalizations include elements, approaches or practices used in creating and evaluating algorithms. CT can be promoted without the use of a computer, but the strategies shaping CT go beyond the era of computers (Caeli & Yadav, 2020; Denning & Tedre, 2019). Caeli and Yadav (2020) show that CT is linked to programming, but also founded on unplugged approaches to problem solving, and argue that analogue programming can be helpful for learning CT. Operationalizations of CT vary based on context. However, the basic understanding of CT, common to most widely used definitions, include *decomposition* of a problem so that it can be solved by parts, ability to use *abstraction* for identifying similarities between problems and solutions, understanding and using *algorithms* for describing procedural completion of tasks as well as working iteratively and in parallel, basic programming concepts such as the use of *variables*, *loops and conditionals* to control algorithms and *debugging* to systematically find and correct errors (Grover & Pea, 2013; Shute et al., 2017). Some CT frameworks aim at particular uses, such as that of Weintrop et al. (2016) specifying CT in the context of science and mathematics education. Brennan and Resnick (2012) include CT perspectives for using computation to express oneself, relate computation to real life problems and connecting with others through e.g., the Scratch online community for which their framework is developed. The framework of Shute et al. (2017) is based on other frameworks and applicable for programming in several contexts, and therefore often used as a practical operationalization for CT.

Descriptions of CT implementations in TE in the literature have "a heavy focus in developing PSTs' CT content knowledge rather than pedagogical practices around CT" (Ottenbreit-Leftwich et al., 2021, p. 156), and recommendations for how to implement CT in TE varies in the literature. Rao and Bhagat (2024) point out the importance of PSTs experiencing CT activities themselves. Delyser et al. (2018) call for the implementation of computer science for PSTs as a subject in TE, rather than in computer science departments. In a European context, Bocconi et al. (2016a) identified integrating CT into modules on problem solving and critical thinking, or PSTs working with pseudocode to produce teaching artefacts as promising ideas for TE.

The most common approach to CT education in recent TE literature, is through programming, followed by robotics (Ausiku & Matthee, 2021), which are also common approaches in elementary and secondary school (Hsu et al., 2018). In elementary and secondary school, CT education is commonly implemented as project- and problem-based learning and as collaborative learning (Hsu et al., 2018). CT courses form the main method in TE, and tend to favour theoretical learning, but some studies propose supplementing with programming tools, robotics, and other physical tools to translate the theoretical knowledge into classroom practice (Dong et al., 2023). Ausiku and Matthee (2021) argue that unplugged activities contribute to PSTs understanding of CT.

Rajapakse Mohottige et al. (2024) found that there are challenges on different levels when Norwegian teacher educators described implementation of CT in TE in mathematics and natural science. Challenges were insufficient coherence between policy and practice, lack of time and professional development, and the PSTs' insufficient knowledge of mathematics (Rajapakse Mohottige et al., 2024). The process of becoming a teacher is messy, recursive, and emotional (Steadman, 2021), and what characterizes TE is that those who are taught, must also learn to teach (Iskov, 2020). The implementation of CT in TE is challenged by the general questions in TE of how theory and practice are integrated and how TE can be experienced as coherent and meaningful by PSTs (Darling-Hammond, 2014). Although there lately has emerged research on the pedagogy of TE, often referred to as "dual didactic perspective" or a "second-order pedagogy", the field is still fragmented and vague (Korthagen, 2016). Second-order pedagogy here refers to the teaching of teaching skills.

Iskov (2020) presents a model for exemplary teaching which can contribute to teaching in TE. It can be used for exemplary TE practice in three distinct meanings. The first are *implicit modelling* where teaching is exemplary in the sense that there is consistency and interaction between the pedagogical justifications, conditions, and decisions of TE. The second meaning are *explicit modelling A,* where the teacher educator references theory, unfolds and exemplifies how it is exemplary by being internally aligned. The third meaning are *explicit modelling B,* where the teacher educator references theory, unfolds and exemplifies how it is exemplary and relevant for PSTs' later teaching (Iskov, 2020). As PSTs are generally unfamiliar with CT and need to learn both CT content as well as pedagogy, the use of programming activities suitable for school may provide exemplary teaching in line with the ideas of Iskov (2020). Dong et al. (2023) propose training methods and tools in TE and a process of practice, reflection and evaluation in school practice, and a such process might contribute to the teaching becoming explicitly exemplary.

Methodology

To answer the research questions, we conducted a scoping review (Arksey & O'Malley, 2005) to allow for a broad variety of studies as our data. Our first step was to define the research area and develop the research questions, and then planning search terms and inclusion/exclusion criteria. From the identified relevant articles, we extracted the data connected to the research questions for analysis.

Search and screening process

The search was done as a part of a larger project, *Mathematics, Science and Computational Thinking* (MASCOT). MASCOT aims to develop knowledge about teaching, learning, and assessing CT in Nordic TE and schools. In MASCOT, a systematic literature search for CT in primary, secondary and TE was done (see Frågåt et al., 2023). To identify relevant studies, we searched Scopus, ProQuest, Web of Science, ACM Digital Library, ERIC, Academic Search Ultimate, Education Source, Teacher Reference Center, IEEE Xplore, and JSTOR. We only included English language peer reviewed journal articles, from 2012 to May 2023, which reported on empirical studies. The current review extracts articles dealing with TE, producing a narrower selection using the following search terms ("Computational thinking" OR CT OR "Algorithmic thinking" OR "Problem solving") AND (Programming OR Coding) AND ("Teacher education" OR "Teacher training" OR "Professional development"). Only articles that *explicitly* address CT are included in this review. Studies from the field of for instance programming were excluded if the study did not refer to CT.

We screened the articles in two phases. All articles were screened, based on abstracts, by two independent researchers. Inclusion criteria were whether the study was about CT, as well as primary, secondary or TE, and mathematics, natural sciences, technology, arts and crafts or music. The main search was conducted in April 2022 and after screening of abstracts, resulted in 16 articles about TE and CT. The search was updated in May 2023 for a total of 34 articles about TE and CT, based on abstracts.

The 34 articles were then read in full by pairs of the authors. All authors read half of the articles, and inclusion/exclusion discussed in the pairs. The inclusion criteria were: the article should present an understanding, definition or presentation of CT and be about TE for mathematics, natural science (biology, physics, chemistry, general science), technology (including computer science), technology comprehension (including educational technology courses). We excluded articles not about TE, courses in higher education not given as a part of TE, and professional development programmes for teachers or primarily related to the subjects music, and arts and crafts. If the study had both PSTs and practicing teachers, the article was included.

The second step of the screening process resulted in 31 articles relevant for this review (see Appendix 1). As the aim of this review is to scope the research in the field of CT in TE, all articles meeting the thematic inclusion criteria were included. The 31 studies are of varying size and quality. But as our interest is not in evaluating or summarizing findings, their quality has not been assessed systematically.

Analysis process

We used qualitative content analysis (Hsieh & Shannon, 2005), and after reading the first 18 articles, all researchers discussed what elements were useful to answer our research questions. We created a table where all articles had one row and the columns contained information on year and country of origin, participants in the study and level of TE, information on the methodological approach, views on CT, research questions, teaching methods and second-order pedagogical approach. This table was then filled out for all articles by pairs of researchers and used for further analysis. Summative content analysis (Hsieh & Shannon, 2005) was used to describe information directly given in the articles, such as country, methods etc. The rest of the analysis was performed with a conventional content analysis (Hsieh & Shannon, 2005), where the authors developed the codes inductively.

To answer what characterizes research on CT in TE, we explored the methodological approaches and context information as well as the studies' research questions. The articles were coded for research methods used in the analysis (qualitative, quantitative or mixed), and type of TE (e.g., for primary or secondary school). Additionally, conventional content analysis (Hsieh & Shannon, 2005) was used to determine which subjects were discussed or used as examples when teaching modules were described and to determine the studies' rationales for including CT in school. Here two authors read and coded the articles first separately, and then conferred and agreed on common codes.

In our initial coding process of the research questions in the articles, we first listed the research questions of the individual studies. Two authors then inductively coded, by reading research questions individually and suggested and argued for codes, to get a fine-grained picture of the research interest mirrored in the research questions. All authors discussed the suggested codes, the codes were compared, and we agreed on a final coding system for the research questions. This was then applied to the 31 articles by two authors.

To analyse how research on CT in TE addresses the challenge teaching CT in school, we coded the articles for what kind of technology or approach for CT education the PSTs worked with (e.g., analogue programming, Scratch, BlueBot, Python, robotics, or other kinds of programming tools), and the described second-order pedagogical approach for teaching and learning CT. For coding the second-order pedagogical approach, two authors developed codes inductively, based on the whole article text. They studied the planned and conducted teaching of the PSTs as well as the questions posed to PSTs during data collection. To maintain a common understanding across the analysis of the research questions and the description of the second-order approach, one author was in both coding groups.

Results

The characteristics of research on CT in TE

The research on CT in TE is characterized by its temporal and geographical distribution, as well as its methodological approaches. Moreover, the rationale for including CT in school as well as the context in which the empirical studies are conducted, and their research questions provide important insight into the field. In the following we only specify the articles when there are four or less, for ease of reading, however the full overview of the coding for all articles is given in Appendix 1.

Distribution over years, countries, and methodological approach

Of the 31 articles, 19 were published in 2022 and there were zero to three articles per year from 2012 to 2021, showing a significant increase in interest, see Figure 1a and Table 1.

Figure 1a and 1b. Left: publication year. Right: articles published per country, created with mapchart.net. Dark colour indicates many publications, and light blue indicates few publications, grey countries have no publications.

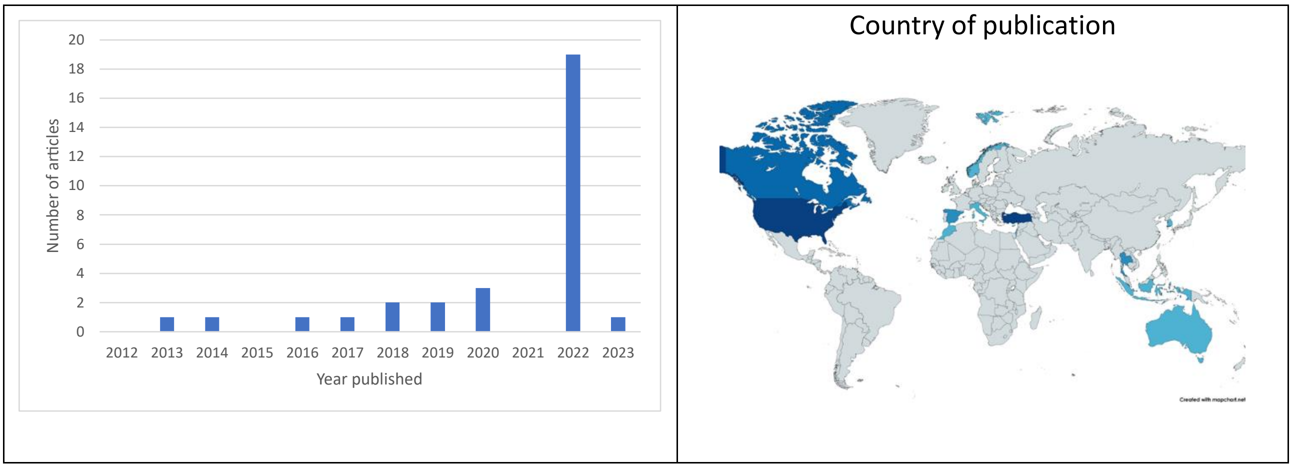

Figure 1b shows the country of origin, and as seen, most published articles are from USA (eight), closely followed by Turkey (seven). There are four articles from Canada, making North America a centre of gravity for this research. The remaining articles are from Morocco and Australia, as well as other countries in Europe and East Asia with one to two articles per country.

Table 1. List of countries of origin for the articles.

Country	Number of studies per country
USA	8
Turkey	7
Canada	4
Spain, Thailand	2
Australia, Cyprus, Indonesia, Israel, Italy, Morocco, Norway, Republic of Korea	1

Thirteen studies apply both *quantitative and qualitative* methods, and there are eight purely *quantitative* and nine purely *qualitative* studies. The studies vary greatly in number of participants from three to 295, with an average of 61. Only seven studies include more than 100 participants, and seven studies include 20 participants or less. The smallest study reporting purely *quantitative* analysis (Sermsri, 2016) includes only 15 participants. One article (Mamolo, Tepylo et al., 2022) does not present data analysis, but tells of five years of experience with teaching CT, presented in a qualitative fashion.

Rationale for including CT in schools

The articles give different reasons for teaching CT in school and therefore in TE as part of their background and theoretical foundations, see Table 2. Most of them argue that CT are skills all pupils need to learn, whereas others focus on the benefits to subjects or give reasons based on government documents or viewpoints in literature. One major set of arguments for CT is based on a view that all pupils need to learn this skill. Many articles cite Wing (2006) stating that CT is an important *thinking skill for everyone*. The importance of everyone developing cognitive skills for problem solving is a recurring argument, as well as the connection of CT to 21st century skills. Arguments are made by some that these skills *should be learned from an early age*, and therefore belong in school. Another frequent argument is that learning CT and programming constitutes a *digital literacy* and that people with this competence are needed in the *job market*. These articles claim an increased need for persons with STEM and computer science competence in a job market which is increasingly computationally intensive, as well as for educating for jobs that do not yet exist.

Another set of arguments for teaching CT is based on its benefits to school subjects. CT is said to play an important role in *science and technolog*y education as scientific practices involve programming (Aalbergsjø, 2022; Gadanidis et al., 2017; Kaya et al., 2020; Vasconcelos & Kim, 2022) and as a means to learning science

(Adler & Kim, 2018; Radloff & Hall, 2022). Five studies argue that CT is part of *mathematics* either by referencing the curriculum (Mamolo, Rodney & Tepylo 2022) or stating that CT is part of mathematical practices (Alqahtani et al., 2022; Mamolo, Tepylo et al., 2022) or claiming that CT supports mathematics education (Gadanidis et al., 2017; Molina-Ayuso et al., 2022). Three studies (Chang & Peterson, 2018; Umutlu, 2022; Zha et al., 2020) argue that CT belongs in *other school subjects* without specifying the subject, or claim it belongs in every subject.

The third, distinct set of arguments for including CT in education is *statements or demands by others*, either literature or curriculum documents.

Table 2. Overview of reason for including CT in school in thematic order corresponding to the text.

Reason	Number of studies
Thinking skills for everyone	15
Should be learned from an early age	5
Digital literacy	12
Economic/job market	9
Science and technology	6
Mathematics	5
Other subjects (not specified)	3
Statements or demands made by others	12

TE context for the studies

Out of 31 studies, 29 evaluate PSTs learning of CT in the context of a CT teaching module of varying sizes, see Appendix 1. Some studies explicitly use the terms intervention or experiment, but nearly all studies evaluate PSTs' learning from teaching modules in TE. A majority of the studies (22) are from TE focused on primary or middle school. Six of these are also concerned with secondary education and the final nine studies do not specify TE level.

The teaching modules are related to different settings and subjects, see Table 3. Eleven studies include CT in courses concerning the use of *technology in education*, eight include CT in *science, engineering and technology* or science education courses, six include CT in *computer science* courses and five studies include CT in *mathematics* courses. Some studies link CT to several subjects, for instance by teaching CT in a computer science course or educational technology course, while using tasks related to mathematics or science (Broza et al., 2023; Cetin, 2016; Pewkam & Chamrat, 2022; Tankiz & Atman Uslu, 2023; Umutlu, 2022), and three studies used language, literature, and art as context (Broza et al., 2023; Tankiz & Atman Uslu, 2023; Zha et al., 2020). The studies from USA generally connect CT to technology in education and science and engineering, whereas the Canadian studies situate CT in mathematics. The Turkish studies focus on school subjects such as mathematics, science and engineering as well as languages and arts in addition to technology in education. Both studies from Thailand (Pewkam & Chamrat, 2022; Sermsri et al., 2022) are related to computer science.

Table 3. Overview of the subject context in TE in which the study is set.

Subject	Number of studies
Technology in education	11
Science, engineering and technology	9
Computer science	6
Mathematics	5

Topics of the research questions

By examining the research questions in the articles, the main interest of the studies is found to be the *PSTs' understanding, learning and knowledge about CT* (14 studies) and *Coding* either digital or analogue (14 studies). Additionally, *PSTs' experience of, attitudes towards, perceptions of, opinions on, and engagement with CT* is addressed in 13 studies. Nine studies also research *CT in subjects* and *CT in connection to transversal skills like collaboration, problem solving and modelling* (9 studies). It is noticeable that only five studies *research teaching skills for CT and computational learning processes*, and only two studies (Molina-Ayuso et al., 2022; Sermsri et al., 2022) are concerned with *assessment*. A great number of the articles include more than one topic of interest in their research questions. Some studies are interested in several perspectives – one study is interested in researching six topics, 23 studies are interested in two or three topics, and seven studies are interested in only one topic.

The five studies which are explicitly interested in how to teach CT in school, addressed different aspects of second-order pedagogy. Adler and Kim (2018) ask whether PSTs want to use CT in their future classroom after incorporating CT in their exercises. This question concerns the PSTs' willingness and motivation to incorporate CT in their own teaching. Umutlu (2022) is interested in what kind of learning activities PSTs design to teach block-based programming and CT in their future classes. The last three study PSTs' understanding or opinions concerning their skills to teach or their conception of this type of practice (Koole & Elian, 2022; Molina-Ayuso et al., 2022; Tankiz & Atman Uslu, 2022).

How research on CT in TE addresses pedagogical practices for CT in school

In order to understand how the pedagogical aspects of CT education are addressed, we analysed the descriptions of second-order pedagogy in the teaching modules and data collection procedures (interviews and survey questions regarding teaching). Despite only five studies explicitly inquiring into the concept of teaching skills in their research questions (Adler & Kim, 2018; Koole & Elian, 2022; Molina-Ayuso et al., 2022; Tankiz & Atman Uslu, 2022; Umutlu, 2022), numerous other studies touch upon this perspective in their description of their intervention and/or findings. These studies give insight into how PSTs learn about how to teach CT. Thirteen studies explicitly include the second-order pedagogy perspective, though the topic is not a focus of the study through a research question. Seven studies include the perspective implicitly, and six studies do not include the second-order perspective. We specify the articles when there are four or less, for ease of reading. The full overview of the coding is given in Appendix 1.

The second-order perspective is addressed in different ways, e.g., by asking PSTs for *reflections on CT and teaching either during the teaching module or in surveys or post interviews,* getting PSTs to *design (and in some studies, implement) teaching of CT in school* or create lesson plans for teaching CT in the 20 studies that address this outside the research question. We also find that the studies report on PSTs being taught through *experiencing technologies relevant for school*, and/or *receive a lecture about how to teach CT*. Together the articles present several ways for how TE can address how to teach CT for PSTs, see Table 4.

Table 4. Different approaches to include second-order pedagogy in the different studies either implicitly or explicitly, in order of appearance in the text. Most of the studies (17) use several approaches.

Second-order pedagogy perspective	Number of studies
Reflections on CT and teaching during the teaching module	8
Reflections on CT and teaching in survey or post-interviews	8
Design for teaching in CT for school	10
Experience technologies relevant in school	20
Receive lecture about how to teach CT	6

One common approach for CT teaching to PSTs, in the five studies explicitly interested in teaching skills in their research questions and the additional 20 studies that address this implicitly, is through highlighting examples and technologies relevant in schools. For instance, Angeli (2022) implemented Lego Wedo Robotics, because this kind of technology by can be used PSTs with pupils.

We find that the teaching interventions described in the articles employ different approaches to practicing CT which are relevant for school, see Table 5. Ten studies combine several technologies and approaches for teaching CT (see Table 7), and that the most common examples are Scratch and other *on-screen block-based coding* environments as well as *physical programming with blocks* of micro:bits, Arduino or robotics. Several of the studies using physical programming are explicitly linked to STEM education. Four of the studies addressing secondary education apply text-based programming (Bati, 2022; Cetin, 2016; Gadanidis et al., 2017; Sermsri, 2016), but not all. There are only two studies explicitly stating that they use text-based programming for primary education (Cetin, 2016; Gadanidis et al., 2017). On the other hand, analogue or unplugged programming is utilized in nine studies.

Table 5. Technology or approach to CT used in the teaching modules described in the articles, in order of appearance in the text.

Approach to practicing CT	Number of studies
On-screen Block-based coding e.g., Scratch	20
Physical programming with blocks e.g., micro:bit, Arduino	11
Text based programming e.g., python	4
Analogue or unplugged	9
Not given or not relevant	3

Our investigation revealed ten studies where PSTs were explicitly instructed to undertake activities related to planning CT teaching. In Esteve-Mon et al.’s (2019) study PSTs first tried unplugged activities and technologies like MakeyMakey, Bee-Bots, mBots and Scratch. At the end of the intervention, the PSTs designed a CT activity for primary school (Esteve-Mon et al., 2019). In only two studies (Alqahtani et al., 2022; Rachmatullah & Wiebe, 2023) did PSTs implement their plans with pupils. For example, in Alqahtani et al. (2022) PSTs were asked to design and implement mathematical activities, for first-grade pupils, that integrated robots.

Interestingly, eight of the studies incorporated a reflective component into their design, requiring the PSTs to contemplate CT teaching practices. This manifested through activities such as composing reflection notes or participating in discussions. Additionally, five studies did not instruct PSTs to engage in reflective practices in their course, but posed reflective questions connected to teaching in surveys or post-intervention interviews, thereby highlighting a distinction between reflective activities and the learning process itself. Three studies are doing both (Aalbergsjø, 2022; Alqahtani et al., 2022; Broza et al., 2023).

Only six studies mentioned teaching PSTs about how to teach CT. For example, Aalbergsjø's (2022) study introduced PSTs to concepts of CT in a lecture and continued afterwards with physical programming using BlueBot, BBC micro:bit, Python-based block-programming using Trinket online coding environment as well as Scratch to create science-related simulations.

To sum up, although only five studies explicitly research how to educate PSTs to teach CT, 13 additional studies incorporate an explicit focus of the second-order pedagogy perspective, and seven studies include an implicit focus. This indicates that teaching in TE, also when it concerns CT, is focused on the fact that PSTs must learn to teach.

Discussion

The characteristics of research on CT in TE

We see a clear increase in research on CT in TE over the last years. The identified articles show a scattered field with more than half of the identified articles from USA, Canada and Turkey. There seems to be little Nordic, and European research. The studies from USA are mainly concerned with CT connected to technology in education and science and engineering, whereas others connect mathematics and computer science to CT. We know that CT as a notion is defined in many ways (Bocconi et al., 2022; Grover & Pea, 2013; Shute et al., 2017), and that the Nordic countries have different rationale and ways of implementing CT in curricula (Bocconi et al., 2018; Pajchel et al., 2024; Tannert et al., 2022). Since the focus in TE in the Nordic is not only on PSTs' own learning of subjects, but on PSTs learning how to teach subjects (Elstad, 2022), we argue that Nordic TE have a unique perspective to add on how to prepare PSTs to implement CT in school. In our analysis we find little trace of the broader understanding of CT that goes beyond computers and programming (Caeli & Yadav, 2020; Denning & Tedre, 2019), although CT as thinking skills for everyone is the most common argument made for CT in education. This argument, however, is closely followed by arguments for digital literacy and employability. This is perhaps because where the studies are conducted influence the rationale for CT.

The studies are conducted in different contexts, with courses on technology in education for primary school PSTs being the most prominent. The methodological approaches used are diverse; while many use quantitative analysis to investigate PSTs' attitudes and skills, there are qualitative studies that go deeper into how PSTs work with and learn about CT.

TE is complex, with tensions and conflicts (Darling-Hammond, 2014; Steadman, 2021). Our review shows that the field of knowledge of CT in TE so far is composed of a number of themes. We find that many studies investigate PSTs’ attitudes, opinions and perceptions of CT, and this may be especially important in TE because PSTs need their learning to be meaningful. Several of the studies research CT in STEM subjects and CT in connection to transversal skills like collaboration, problem solving and modelling It is noteworthy that there are several themes such as student and children’s perspective, democracy and empowerment that are not central to the studies' research questions but are present in our findings concerning the rationale for including CT in schools.

How research on CT in TE addresses pedagogical practices for CT in school

At first glance, there appears to be a lack of studies addressing how PSTs learn to teach CT to pupils, in accordance with previous studies (Delyser et al., 2018; Ottenbreit-Leftwich et al., 2021). However, our review finds that the picture is more complex than that. Many studies include second-order perspectives in different ways, but without a systematic and common approach, and sometimes only implicitly. A recurring approach for second-order perspectives is applying teaching methods and technology applicable for school, thereby making the teaching exemplary, in line with Iskov (2020), but not necessarily explicit modelling of exemplary teaching. The main approaches for PSTs to learn CT is using block-based coding on screen, mainly Scratch, and to a lesser extent physical programming. Physical programming is often explicitly linked to STEM education, as found in previous reviews (Ausiku & Matthee, 2021), possibly because this is an intrinsic component of these subjects. Analogue or unplugged CT activities (Caeli & Yadav, 2020) are also used in several of the interventions. As most of the studies focus on primary and middle school TE, this is perhaps as expected. Ten studies use several technologies and approaches in combination. This wide use of approaches may further strengthen exemplary teaching and PSTs’ repertoire for teaching CT.

Steadman (2021) argues that it is essential that evaluations and innovations in TE are rooted in the actual experiences of the PSTs. We find that many of the studies apply a second-order pedagogy perspective, but there is a lack of common language and systematics for how these different perspectives are concretized. Only five studies explicitly had this as a focus area in their research questions. Together, this points to a research field which is still immature. Iskov's (2020) three specific recommendations for exemplary teaching provide a suggestion for planning, implementing, analysing, and developing teaching for PSTs across disciplines and content areas, while highlighting the connections between school, TE, and the profession. PSTs reflections on CT and teaching, which are part of many of the studies, is one way in which TE can explicitly integrate CT pedagogy.

Interestingly, some studies included tasks where PSTs developed CT teaching modules for school. This could be considered a step beyond the exemplary teaching described by Iskov (2020). However, only two of the studies had PSTs teach pupils. More research is needed on implementations where PSTs gain practical experience with pedagogical practices for teaching CT. It is possible that the quantitative methods used to research the field do not easily give information on second-order approaches. We argue that researchers need to discuss what type of knowledge can be found with these methodological approaches, and whether this knowledge is all that is needed for understanding the complex reality of learning to teach CT.

The present review focuses on research on CT in TE, and how it addresses the challenge of teaching CT in school. Articles that did not explicitly use the notion of CT, were not included, for instance articles which focus on coding or programming without addressing the wider notion of CT. Other search terms than CT, like coding or programming, may provide insight into CT practices in other subjects where CT could take other forms. A further investigation into TE and programming, may provide a more detailed and nuanced picture of the field.

Concluding remarks and implications

The aim of this review was to describe the research on pedagogical practices in CT education for PSTs. We find this to be an area of growing interest, but a field which is not yet mature. We base this on the number of studies in the field and the size of the studies. The centre of research is in North America and Turkey. There are some studies scattered across the world, and the Nordic are not yet well represented.

Most articles include descriptions of second-order pedagogical approaches either through using teaching methods or technology applicable in school or by engaging the PSTs in reflections on CT and teaching. However, the research mainly focuses on PSTs’ CT skills and attitudes, rather than their learning of pedagogical practices for teaching CT. Some studies ask PSTs to develop plans teaching for CT, but only two reported on PSTs being given the opportunity to teach pupils.

We find that the field lacks a common language and systematic approaches for researching pedagogical practices for teaching CT. This signals a need for more research on this topic as well as critical reflection on the quality of research findings in this field. Future research should address the distinctions and similarities between programming and CT education, as well as the distinctness of CT education in different school subject settings. More systematic knowledge about the second-order approaches for CT in TE is needed, both larger quantitative studies on how to learn good pedagogical practices, and deep qualitative studies to understand the “hows” and “whys” of this area. Study of Nordic TE is especially relevant because of its focus on second-order pedagogical practices. Nevertheless, we see the beginnings of a pedagogy for CT in TE, which moves beyond teaching programming and content knowledge about CT, towards how to teach

CT.

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Appendix 1: Tables with articles and codes

Table 6. Overview of coding used in the analysis, part 1.

This includes coding for methodological approach, rationale for including CT in school, and the TE context for the study. Abbreviations used in the table are: qual = qualitative approach, quan = quantitative approach, mix = mixed methods approach, n.a. = not applicable, science = science and technology, edutech = course on technology in education, CS = computer science, TE = teacher education

	Methodology	Number of participants	Thinking skills for everyone	Learned from an early age	Digital literacy	Economic/job marked	Science and technology	Mathematics	Other subjects (not specified)	Statements or demands by others	Teaching module	Primary or middle school	Secondary education	Subject context in TE
Aalbergsjø (2022)	qual	46					x			x	x	x	x	science
Adler & Kim (2018)	qual	52	x	x			x				x	x		science
Alqahtani et al. (2022)	mix	32	x		x			x			x	x		mathematics
Angeli (2022)	quan	50				x					x	x		edutech
Avcı & Deniz (2022)	quan	141	x	x										n.a.
Bati (2022)	quan	38		x						x	x			science
Broza et al. (2023)	mix	24	x		x	x					x	x		edutech
Cetin (2016)	mix	56	x							x	x	x	x	CS
Chang & Peterson (2018)	qual	59	x		x				x		x			edutech
Esteve-Mon et al. (2019)	quan	114			x						x	x		edutech
Gabriele et al. (2019)	mix	141								x	x			CS
Gadanidis et al. (2017)	qual	143	x		x		x	x			x	x		mathematics
Kaya et al. (2020)	quan	35	x			x	x				x	x		science
Kim et al. (2013)	quan	132				x					x	x		CS
Koole & Elian (2022)	qual	22	x		x	x				x	x			edutech
Lloyd & Chandra (2020)	qual	8								x	x	x		edutech
Mamolo, Rodney, & Tepylo (2022)	qual	3						x		x	x	x		mathematics
Mamolo, Tepylo et al. (2022)	n.a.	n.a.						x		x	x	x		mathematics
Molina-Ayuso et al. (2022)	mix	149	x		x			x			x	x		mathematics
Ouahbi et al. (2022)	quan	63			x					x	x	x		CS
Pewkam & Chamrat (2022)	mix	30	x			x					x	x	x	CS
Rachmatullah & Wiebe (2023)	mix	11				x					x	x		science
Radloff & Hall (2022)	qual	52				x	x			x		x		edutech
Sarı, Çelik et al. (2022)	mix	31	x		x						x			science
Sarı, Pektaş et al. (2022).	mix	24			x						x			science
Sermsri (2016)	quan	15				x					x			CS
Tankiz & Atman Uslu (2023)	mix	37	x	x	x						x	x		edutech
Umutlu (2022)	qual	12	x						x	x	x			edutech
Vasconcelos & Kim (2022)	mix	19					x				x	x	x	science
Yadav et al. (2014)	mix	295	x	x	x						x	x	x	edutech
Zha et al. (2020)	mix	15							x	x	x	x	x	edutech
Sum column			15	5	12	9	6	5	3	12	29	22	6	

Table 7. Overview of coding used in the analysis, part 2.

This includes coding for research questions and second-order pedagogical approach. Abbreviations used in the table are: RQ = research question, PST = pre-service teacher, CT = computational thinking

	RQ: PTS' understanding, learning and knowledge	RQ: PTS' experience, attitudes and so on	RQ: CT in subjects	RQ: Coding – analogue and digital	RQ: CT and transversal skills	RQ: Teaching skills for CT	RQ: Assessment of CT	Not RQ, explicitly adressed second-order pedagogy	Implicitly adressed second-order pedagogy	Not adressed second-order perspective	Experience teaching with school relevant examples	Recieve lecture about how to teach CT	Reflections during teaching modules on teaching	Reflections survey/post-interviews on teaching	Design for CT teaching in school	Implemented with pupils	Analogue or unplugged	Block-based on screen	Physical programming	Text based
Aalbergsjø (2022)			x	x				x			x	x	x	x	x		x	x	x	
Adler & Kim (2018)			x		x	x								x				x		
Alqahtani et al. (2022)			x					x			x		x	x	x	x	x			
Angeli (2022)				x				x			x	x							x	
Avcı & Deniz (2022)		x								x										
Bati (2022)	x			x	x					x										x
Broza et al. (2023)		x						x			x		x	x				x		
Cetin (2016)	x	x		x					x		x							x		x
Chang & Peterson (2018)		x						x			x		x				x	x	x	
Esteve-Mon et al. (2019)	x							x							x		x	x	x	
Gabriele et al. (2019)	x	x						x			x	x			x			x		
Gadanidis et al. (2017)		x	x					x			x	x	x				x	x	x	x
Kaya et al. (2020)		x		x				x			x	x	x					x	x	
Kim et al. (2013)	x				x					x							x			
Koole & Elian (2022)		x			x	x					x		x		x			x		
Lloyd & Chandra (2020)		x		x						x								x	x	
Mamolo, Rodney, & Tepylo (2022)				x	x				x		x			x				x	x	
Mamolo, Tepylo et al. (2022)			x	x					x		x							x		
Molina-Ayuso et al. (2022)	x			x	x	x	x				x							x		
Ouahbi et al. (2022)				x				x			x				x			x		
Pewkam & Chamrat (2022)	x								x		x						x	x	x	
Rachmatullah & Wiebe (2023)		x	x					x					x		x	x	x			
Radloff & Hall (2022)	x			x						x										
Sarı, Çelik et al. (2022)	x	x			x				x		x			x					x	
Sarı, Pektaş et al. (2022).	x		x	x					x		x			x					x	
Sermsri (2016)					x		x			x							x			x
Tankiz & Atman Uslu (2023)	x	x				x					x				x			x		
Umutlu (2022)	x			x		x									x			x		
Vasconcelos & Kim (2022)			x	x	x			x							x			x		
Yadav et al. (2014)	x	x						x			x	x								
Zha et al. (2020)	x		x						x		x			x				x		
Sum column	14	13	9	14	9	5	2	13	7	6	20	6	8	8	10	2	9	20	11	4