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Developing preservice teachers' understanding of computational thinking: A constructionist approach

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Abstract

Research relating to the development of computational thinking (CT) at primary school level is still in its infancy despite indications that it is most effective when introduced in primary/early secondary education. Teachers are pivotal to ensuring children develop CT, so it is essential they are effectively prepared, starting at preservice level, to incorporate CT into pedagogical practices. Grounded in constructionist principles and adopting the stance that CT be developed as part of subject areas other than computer science, this qualitative study presents findings focused on the understandings of CT of 51 preservice teachers who engaged in a digital learning specialism. Carried out over a 2-year period, the research investigated preservice teachers' understandings of CT and how the design of the specialism helped to develop their understanding. Findings highlight deep understandings of CT among the preservice teachers who were able to make connections between constructionism and the development of CT. They also demonstrated a high level of pedagogical knowledge, indicating they understood why they designed particular challenges for children as part of their classroom experience. Findings

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are relevant for the design of teacher preparation programmes illustrating how CT can be effectively embedded to combine theory and practice.

KEYWORDS
computational thinking, constructionism, learning design, preservice teachers

Practitioner notes

What is already known about this topic

- Existing research base in relation to preservice teacher education and computational thinking is limited.
- When computational thinking is introduced as part of initial teacher education, preservice teachers:
  a. develop more accurate and increased understandings of computational thinking
  b. demonstrate more positive attitudes towards the implementation of computational thinking in the classroom.
- Duration of module seems to be a significant factor. A 1-week module might be enough to develop preservice teachers' surface-level understanding of computational thinking, but it would not provide them with enough knowledge to embed computational thinking in meaningful ways in the classroom (Yadav et al., 2014).

What this paper adds

- Adopting the stance that computational thinking should be developed as part of subject areas other than computer science.
- This paper presents and discusses findings from the implementation of a model for preservice teacher education grounded in constructionism, that supports preservice primary teachers in building an understanding of CT as well as the pedagogical knowledge necessary for embedding CT into their classroom practice.

Implications for practice and/or policy

- The insights gained from this study are particularly relevant for the design of teacher preparation programmes indicating how CT can be effectively embedded to combine theory and practice.
- This will ensure that CT concepts are not developed in a decontexualised manner but are embedded within the prescribed curriculum in a relevant and meaningful manner.

INTRODUCTION

There has been increasing interest in engaging primary school students in computational thinking (CT), with many countries around the world making formal efforts to include CT as part of compulsory primary education (Bocconi et al., 2016; Gretter & Yadav, 2016; Lee et al., 2020; Yadav et al., 2011). Despite this, the development of CT at primary school level is an area of research still in its infancy (Angeli et al., 2016). As a concept, consensus has not been reached on how CT should be defined. Nor is there agreement on how CT should be introduced at primary level.

Irrespective of the stance taken, it is agreed that the teacher is a critical factor towards ensuring CT is embedded in any subject area (Barr & Stephenson, 2011; Voogt et al., 2015; Yadav et al., 2017) and accordingly, that teachers should be adequately prepared to include CT as part of their classroom practices (Lye & Koh, 2014; Yadav et al., 2017). Moreover, this preparation should begin at preservice level (Barr & Stephenson, 2011; Yadav et al., 2017). This approach will ensure preservice teachers not only develop understandings of CT but are also introduced to ways they can design learning opportunities for their students to develop CT (Wing, 2016).

To date, limited work has been carried out on how best to prepare preservice teachers to embed CT in their future classrooms and while there is much to be learned from this body of research, it also leaves some unexplored issues relating to the format of this learning. Extant studies suggest that where learning about CT is introduced as part of initial teacher education, preservice teachers develop more accurate and increased understandings of CT and also feel more positive towards the implementation of CT in the classroom (Adler & Kim, 2018; Bean et al., 2015; Chang & Peterson, 2018; Jaipal-Jamani & Angeli, 2017; Yadav et al., 2014; Zha et al., 2020). However, the studies equally suggest that preservice teachers require a more extended exposure in order to develop deeper understandings of CT and to strengthen their self-efficacy. In each of the study retrieved, classes or workshops ranged from 50 minutes to 3 hours in duration and preservice teachers had no more than two classes in total. This led Yadav et al. (2014) to conclude that while the results in her study were promising; and the module (2*50 minute classes) might be enough to develop preservice teachers' understanding of CT, it might not provide them with enough knowledge to embed CT in meaningful ways in the classroom. The study also found that preservice teachers with no previous exposure to CT only developed surface-level understandings. Similarly, findings from Zha et al.'s (2020) study did not provide evidence that the short exposure to CT improved their self-efficacy. Taken together these studies imply that careful consideration and planning must be accorded to how preservice teachers should be effectively introduced to CT so that they not only develop content knowledge but also their pedagogical knowledge. As part of this planning, attention must be accorded to the instructional, curricular and pedagogical implications for teacher preparation (Lye & Koh, 2014; Yadav et al., 2017).

Adopting the stance that CT should be developed as part of subject areas other than computer science, the authors developed a specialism in Digital Learning as part of the Bachelor of Education (B.Ed) degree at the Institute of Education of Dublin City University (DCU IoE). Grounded in constructionist principles, the specialism sought to develop preservice teacher understandings of CT in a progressively developmental manner culminating with the preservice teachers embedding CT with children in a primary school classroom and within the context of the primary school curriculum. Carried out over a 2-year period, the research reported in this paper sought to investigate the preservice teachers' understandings of CT on completion of the specialism and how the design of the specialism helped to develop their understanding. The authors designed and taught the Major Specialism and also carried out the research.

REVIEW OF LITERATURE: COMPUTATIONAL THINKING IN A CONSTRUCTIONIST LEARNING ENVIRONMENT

Computational thinking

Originating in the work of Seymour Papert (1971, 1980), CT has steadily gained prominence as a way of thinking about solving complex, open-ended problems. Over four decades ago, Papert introduced the 'idea of the computer being the children's machine that would allow them to develop procedural thinking through programming' (Dede et al., 2013, p. 2), enabling them to combine critical thinking with computing power as the foundation for innovating solutions to real-life problems (Tabesh, 2017). Specifically, he emphasised the role of computing and computational ideas in facilitating learning and believed that computing could be a powerful intellectual tool for all children,

> …something children themselves will learn to manipulate, to extend, to apply to projects, thereby gaining a greater and more articulate mastery of the world, a sense of the power of applied knowledge and a self-confidently realistic image of themselves as intellectual agents. (Papert, 1971)

For Papert, CT is therefore more than just a problem-solving process as it requires learners to solve problems algorithmically and develop a level of technological fluency and language as they learn to communicate and express their ideas with the language of code (Papert, 1980).

Several decades later, Wing's seminal paper in 2006 reintroduced the term stating that CT was not just programming but rather a 'fundamental skill' for everyone. She defined it as the thought process of formulating and solving problems by 'drawing on the concepts fundamental to computer science' (p. 33) when 'equipped with computing devices' (p. 35). Within this broader context, she outlined the central components of CT, including algorithms, abstraction, decomposition and automation, all of which can be found in many contexts and disciplines and which assist learners in developing to approach and solve problems in a systematic way.

With the growing ubiquity of technology, CT has received considerable attention since 2006 including at school level. But, although scholars have continued to build on the work of Wing and have described CT in a variety of ways, consensus has not been reached on a definition of CT. This is viewed as problematic and the need for more consistent definitions of CT, both for its inclusion in education and for driving integration into school contexts is strongly argued (Grover & Pea, 2013; National Research Council, 2011). The extant body of work does, however, serve to identify a range of skills associated to practices in primary and post primary classrooms (eg, Angeli et al., 2016; Chen et al., 2017; Selby & Woollard, 2014; Shute et al., 2017; Voogt et al., 2015). Elements that are widely accepted include abstraction, generalisation, decomposition, algorithmic thinking, debugging and iteration (See Table 1).

Computational thinking in a constructionist learning environment

The central tenet of constructionism, is that learning is facilitated by constructing tangible artefacts or objects that can then be shared and discussed with others (Papert & Harel, 1991). The learners are accordingly viewed as active builders of their own knowledge as they engage in constructing artefacts using a range of computational materials. These artefacts become their 'objects to think with' (Papert, 1980, p. 12) and support the development of concrete ways of thinking and learning about CT concepts and practices (Brennan & Resnick, 2012). The ability to manipulate these objects, to repeatedly make adjustments and refinements or experiment with them to see how they work lends itself to a concrete style of reasoning (Turkle & Papert, 1992). This, as argued by Papert changes the process of learning to one which is iterative and cumulative, embracing both planning and bricolage styles.

Constructionism also draws attention to the social nature of learning, noting that activities such as making, building or programming through which the learner produces artefacts that others can see and critique provide a rich context for learning. The artefacts are a means by which others can become involved in the thinking process, while at the same time the

TABLE 1 Core elements of CT (taken from Angeli et al., 2016 and Shute et al., 2017)

Elements	Definition
Abstraction	Entails reducing unnecessary details, highlighting the relevant details to make the process simpler and easier to understand. Leads towards creation of a model/representation to solve a problem
Algorithmic thinking	Devising a step-by-step solution to a problem. Includes: algorithm design: planning an algorithm, sequencing actions correctly; parallelism; efficiency; and automation
Decomposition	Breaking down complex problems into manageable smaller problems or into their component parts so that each part can be understood and solved separately. Overall solution is reached by assembling collections of smaller parts (Csizmadia et al., 2015)
Generalisation	Looking for a general approach to a class of problems. Ability to identify common patterns between older and newer problem-solving tasks and use sequences of instructions previously employed, to solve a new problem (reusing and remixing). Is a way of solving new problems based on previous solutions to problems, and building on prior experience Csizmadia et al., 2015)
Debugging	Skill to identify, remove and fix errors
Iteration	Iteration refers to repeating the problem-solving process to refine the solution towards an optimal solution

learner's thinking benefits from multiple views and discussions (Butler, 2007). Through peer feedback or group discussions, for example, learners are both encouraged to articulate their thinking as well as to understand and incorporate the the perspectives of others. In this way, the artefacts or 'objects to think with' provide a link between sensory and abstract knowledge and between the individual and the social worlds. Moreover, shared knowledge is constructed when artefacts and shared understanding are coupled through cycles of representing and interpreting using an incremental spiral approach, engaging in conversation around their own or another's artefact in each cycle, the development of a shared understanding is enabled and the foundation for new understandings were cultivated in progressively deeper ways. (Ackermann, 2001). Turkle and Papert (1990) refer to this 'validity of multiple ways of knowing and thinking' as 'an epistemological pluralism' (p. 129).

From a constructionist perspective, CT is in line with Papert's viewpoint; that is, CT is both a skill to learn and a way to learn—'to create, discover, and make sense of the world, with digital technologies as extensions and reflections of our minds'. (Cator et al., 2018, p. 21). However, in keeping with Papert's idea of engaging with 'powerful representations', what is essential to consider when designing a learning environment is not so much what programming language and/or computational materials to use, but what personally meaningful ideas the programming language and materials can enable the learners develop and how those ideas will develop CT and form new ideas about the subject area (eg, mathematics and science). Furthermore, activities and learning situations should be developmentally appropriate for the learners and grounded in meaningful contexts (Butler, 2007).

Drawing all of these ideas together, the design a learning environment—in this case, a specialism in digital learning for BEd students which would develop understandings of CT—must embrace a *process* of building, both in the sense of building artefacts and building new understandings. This had implications for all aspects of the design of the digital learning specialism and formed the theoretical framework of the specialism. As illustrated in Figure 1, the design of the specialism was planned so that (i) learners would be: actively engaged in constructing artefacts using a range of computational materials, (ii) the artefacts would become "objects to think with" and thus support concrete ways of thinking, (iii) the facility to manipulate the objects created would support an iterative and cumulative process of learning and (iv) through discussion of which would allow others to become involved in the thinking process.

DESIGN OF THE SPECIALISM IN DIGITAL LEARNING

A Specialism on the BEd (Primary) degree in DCU comprises of five modules (5 * 5 ECTS) taken over years 2, 3 and 4 of the programme. Each module runs for 2 hours per week for 12 weeks. The overarching aim of a specialism is that preservice teachers develop deep subject knowledge and leadership skills in a specific area which will allow them to make a strong contribution to curriculum development and innovation in schools on graduation (BEd Accreditation Document, 2012). The Specialism in Digital Learning accordingly targets the deepening of preservice teachers' content knowledge and pedagogical knowledge of CT. This challenge is complex as we need to develop the pre-service teachers' understandings of constructionism and constructionist learning environments, CT, computational tools and also how to make connections to the content of the primary school curriculum.

Grounded in the constructionist principles outlined previously, our approach across the specialism is to engage preservice teachers with the concepts of CT using a range of computational materials (eg, BeeBots, Kibo, Scratch Junior, Scratch, Lego WeDo); enable them to build their own interpretation based on experience, literature, class discussions and hands-on learning experiences; and finally, to make learning concrete and relevant through the completion of assignments that relate to their own learning, their future teaching and the Primary School Curriculum (GOI, 1999). Personal reflection, peer feedback and group discussions are key features of modules as it is through engaging in conversation around their

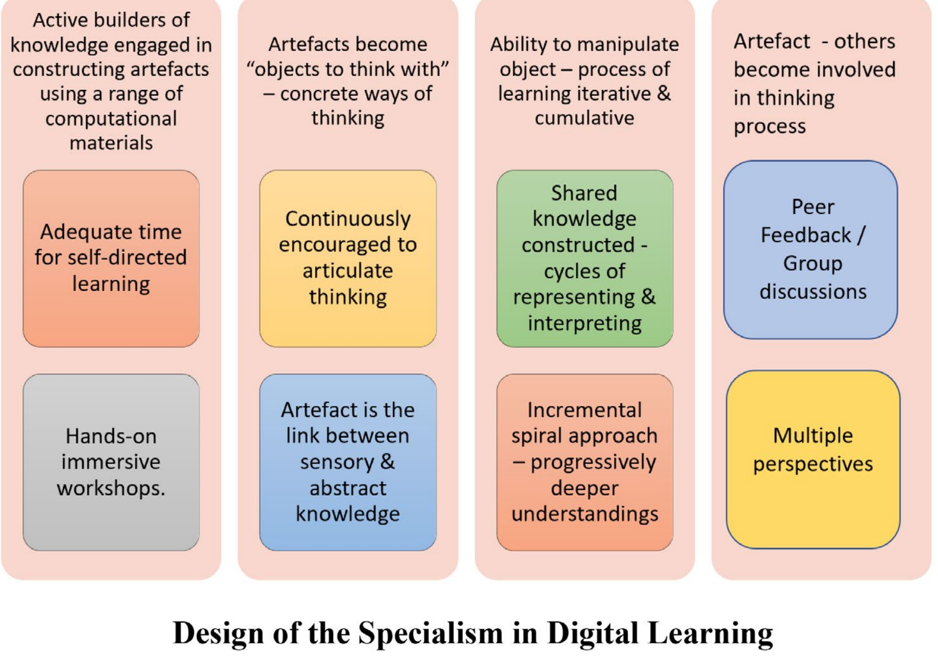

FIGURE 1 Theoretical framework underpinning the Specialism in Digital Learning: a skill to learn and a way to learn [Colour figure can be viewed at wileyonlinelibrary.com]

own or another's artefact (be it a programme in Scratch or a Lego robot) that, the development of a shared understanding is enabled and the foundation for new understandings laid.

An incremental spiral approach is adopted across the design of the modules in which the key ideas and concepts in relation to CT and constructionism are returned to, in increasingly deeper and more complex ways (Bruner, 1960). For example, initial modules focus on understanding the key ideas in CT and the identification of CT in programming activities completed as part of their coursework eg, creating stories and games using Scratch and in building and programming robots using Lego WeDo. By the final module, the preservice teachers put their understandings of CT ‘into action’ when they engage in a small-scale project with a group of children in a primary school (See Table 2). Module assessments are also designed to promote increasingly deeper engagement. Initial assignments focus on personal reflections on their own learning in relation to CT, moving towards connecting this to the big ideas in the literature in relation to constructionism and CT and finally rooting these ideas to their classroom practice by engaging in a small group research project in local primary classrooms.

The final module, is designed to enable preservice teachers to translate their learning into practice (Teaching Council, 2017) and also afford them an opportunity to engage in research, thus providing ‘the foundation of their practitioner-based enquiry stance in the future’ (Teaching Council, 2017, p. 23). As part of the module; preservice teachers in groups of three, are required to design and implement a series of three 2-hour workshops in which they introduce coding and CT concepts using Lego WeDo robotic materials to fourth or fifth class children (aged 10–11 years) in local schools, within the context of the primary school curriculum. For example, in 2018 and 2019, the projects were conducted as part of primary science and in particular, the Design and Make strand of the Primary School Science Curriculum (GOI, 1999). This subject area was selected as it had been the focus of the

TABLE 2 Overview of modules in the digital learning specialism

Years	Modules	Key concepts	Computational materials	Assessment
2	Design & build to learn	Introduction to CT skills and constructionist learning environments	BeeBots, Kibo, Lego WeDo, Micro:Bits	Reflective Blog—personal learning in relation to CT and principles of constructionism
3	Gaming to learn	CT in coding	Scratch; Minecraft	Design of complex game in Scratch. Literature informed essay on CT and application to individual coding practices
3	Creative construction	Constructionist learning theory Curriculum integration of CT: STEM	Lego WeDo	Design of artefact to solve real-world problem and Reflective Blog personal learning in relation to CT and principles of constructionism
4	Designing & learning with digital technologies	Embedding constructionist principles and CT within the primary classroom Recording of learning observed	Lego WeDo	Design of series of classroom CT workshops embedded in a curriculum area informed by constructionist principles. Essay based on CT and the learning observed

Creative Construction Module. As part of their project work in schools, the preservice teachers use participant observation as a data gathering mechanism. Consistent with the iterative and incremental nature of constructionism, the preservice teachers' classroom experiences, in turn become their 'object to think with' as they reflect on their experiences each week and engage in reflective group discussions to analyse their observations. The discussions are structured to enable preservice teachers to connect theory with practice and to further deepen their understandings of both CT and constructionist learning theory.

RESEARCH DESIGN

The aim of this study was to investigate preservice teachers' understandings of CT on completion of the specialism in digital learning as part of their BEd degree and how the design of the specialism helped to develop this understanding.

Participants and context

Fifty-one preservice teachers who had completed the Specialism in Digital Learning participated in the study which was carried out over 2 years. Eighteen participated in Year 1 (15 females and 4 males) and 24 in Year 2 (20 females and 4 males). All were unfamiliar with CT and did not have prior experiences with computer programming at the outset of the specialism.

As part of the final module described previously, the preservice teachers in groups of three worked with pupils in four local schools:

- School A: 2 × Fourth Classes (approximately 30 boys in each class each year)
- School B: 1 × Fourth Class & 1 Fifth Class (approximately 30 girls in each class each year)
- School C: 1 × Fourth Class (approximately 30 boys & girls in class each year)
- School D: 1 × Fifth Class (approximately 25 girls in class each year)

Methodology

The research was carried out on completion of the specialism and data collection focused on the final module of the specialism. A qualitative approach was adopted in the research and data collection methods included document analysis and group interviews:

- Each of the 51 preservice teachers completed reports of their classroom-based research (numbered 1–51) as part of the final module. These reports took the form of traditional research reports containing a literature review, methodology, findings and discussion sections. Findings typically described the development of two or three of the elements of CT observed during the classroom projects and which were presented as 'themes'. The preservice teachers gave the authors permission to use these reports as part of the data corpus.
- Group interviews were carried out approximately a month after the competition of the final module, to probe the preservice teachers' experiences, understandings and reflections in relation to CT. Each interview, lasting approximately 20 minutes, was conducted by the authors with between six and eight preservice teachers. Interviews were conducted face to face in Year 1 and online in Year 2 (due to COVID-19 restrictions). Fourteen preservice teachers participated in Year 1 and 24 in Year 2.

A three-step approach was adopted towards data analysis:

1. Data from Year 1 were analysed and presented as a set of findings (Butler & Leahy, 2020).
2. Data from Year 2 were analysed and reduced to a set of findings.
3. Analysis was carried out across Year 1 and Year 2 in order to identify a final set of themes.

Grounded theory methods (Charmaz, 2014) were used to code the data, although the approach was influenced by theory; namely, the literature relating to CT and constructionist learning theory. The emergent codes were, therefore, influenced to some degree by pre-existing theory but they were not wholly determined by theory. Overall, decisions were driven by the data and, as necessary, new categories of adjustment added until the final set of categories emerged. These were then collapsed into a set of overarching themes that were believed to represent the preservice teachers' understandings of CT along with their perceptions of how the design of the specialism in digital learning helped to develop this understanding.

Initial coding of the preservice teacher reports was carried out inductively and individually by the authors who then worked together to reduce the initial list of codes into a set of overarching themes that were deemed to answer the research question. Where necessary, some of the data were quantified and presented as tallies; for example, the frequency that the core elements of CT were included as themes in the preservice teacher reports. This quantification was believed to add further insight into their emerging understandings of CT. Reflecting the constructionist view that CT is both a skill to learn and a way to learn, two overarching themes emerged. The first relates to the understanding of CT as demonstrated by the preservice teachers and the second to their perceptions of how the design of the specialism in digital learning helped to develop this understanding. These are presented in the section that follows.

FINDINGS

In presenting the findings only a small number of data extracts that are representative and illustrate the findings most clearly are presented due to restrictions of word count. *Additional data extracts for each section in the findings are included in the supplementary material (SM) which will be referenced by indicating the cell number in the spreadsheet (eg, SM:C6)*.

Understandings of CT

The ability of the preservice teachers to identify CT in the children they engaged with over the 3 weeks of the project, as well as their knowledge of how to develop children's CT were interpreted as indicators of overall understandings of CT (cf. Table S1). Through engaging with the children, the preservice teachers not only further deepened their understanding of CT but in the process developed their ability to design a learning environment and plan the strategies required so that their students in turn would develop CT.

Ability to identify CT in children's practice

As part of their write-up following the class-based project, the preservice teachers were asked to present two or three emergent themes with supporting evidence from their experiences.

Across the two cohorts, the most prominent themes presented were algorithmic thinking (30%), decomposition (25%) and debugging (24%). Abstraction (14%) and generalisation (7%) were reported to a lesser extent. The emergence of this pattern was similarly explained in each of the focus groups; 'I think we saw some of them and not others. … and it was kind of the same ones coming up all the time … algorithmic thinking, debugging, decomposition, abstraction' (Focus_Group#3) (See Table 3 and Figure 2).

Analysis highlighted strong understandings of CT, particularly in relation to algorithmic thinking, decomposition and debugging. This was demonstrated through their ability to identify and track the development of components of CT among the children they engaged with across the duration of the project. They also exhibited some understanding of the interrelationship between the components of CT and of the connections between constructionism and the development of CT.

Preservice teachers' understanding of CT was evidenced through the examples they presented in their written accounts, the majority of which began by signalling the children's limited or lack of a skill. For example, limitations in relation to decomposition and debugging are highlighted in the following extract. (also cf. SM:C6)

> At first, the children became quite overwhelmed by the number of small tasks involved in larger tasks. For example, when programming Milo to move to one end of the table and back, the children, rather than breaking this down into sizeable portions, became frazzled and 'stuck'. (PST#19)

TABLE 3 The number of preservice teachers who included each element of computational thinking in the write-up of their classroom experience

	Abstraction	Decomposition	Generalisation	Algorithmic thinking	Debugging
# preservice teachers in 2019	9	11	4	10	7
# preservice teachers in 2020	4	12	2	18	15
Total	13	23	6	28	22

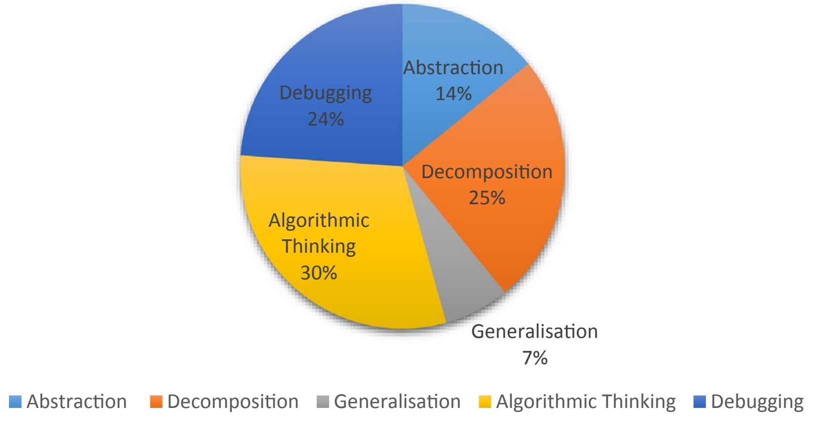

FIGURE 2 Distribution of the elements of computational thinking observed in classrooms as foregrounded by the preservice teachers [Colour figure can be viewed at wileyonlinelibrary.com]

In contrast, the following extract document the children's developing skills, describing an approach to decomposition, the debugging practices observed (exploration/trial & error) as well the step-by-step approaches adopted in specific tasks (also cf. SM:E7).

> … three of the groups showed early stages of the skill [debugging]. … One team in particular, then began to look at their code and tried to find where the error was. Through trial and error, they came to the conclusion that the arrows on the motor direction had something to offer to their problem. They then had a discussion around what they could mean and began to explain how they visualised the motor working when using each block, both arguing in favour of the opposite block. To decide on which block was correct, they created two sample codes, one using the clockwise, and the other using the anti-clockwise motor block. After testing the two codes, they concluded that the clockwise code made the machine move forward as they had hoped. …Through discussion and debugging, this team identified their problem, tried various ways to fix it, found the root of the problem and in turn, found a solution. (PST#16)

Finally, the depth of the preservice teachers' understandings was illustrated through their ability to make interconnections between the elements of CT as well as their ability to make connections between the development of CT and constructionism. More specifically, many of them identified that the ability to manipulate the objects created, supported the development of concrete ways of developing CT (ie, 'objects to think with').

> The 'object to think with' had a symbiotic role to play with debugging as it allowed children to physically see how the code ran with their robotic build. This allowed them to discuss issues which arose, possible solutions and visually explore the different possibilities of coding blocks during the trial and error phase. (PST#23)
>
> (also cf. SM:C10/G10)

Knowledge of how to develop the children's CT

In addition to identifying elements of CT in the children's work, the preservice teachers also demonstrated knowledge of how to develop the children's CT, indicating that they understood why they were designing particular challenges that they set for the children ie, to develop specific aspects of CT. This entailed the identification of gaps in the children's knowledge of CT, the use of targeted activities as well as the utilisation of teaching strategies such as modelling, questioning and gradual withdrawal. This was summarised in Focus Group#1 where it was noted that because 'you knew about CT before you went into the school. When you went into the school, you were able to identify skills in the children's practice, but you were also able to identify those that were missing, and then you were able to plan how to begin to develop those skills'.

Observations and reflections after each class informed planning for the following week in that 'All of the data we collected (observation templates, evidence sheets etc.) … informed some of our decisions for the following lessons and observation days' (PST#30). Across the groups, this tended to focus on the development of a particular CT skill/element. The following extract (Figure 3) is representative of the reflection and planning that occurred. In this instance, the group of preservice teachers had identified that the children were 'not using the skill of decomposition when they were faced with problems within their construction and programming'. Consequently, they targeted this skill in the subsequent activity by focussing the children's attention on breaking down the task into manageable steps.

Strategies used to develop CT in children

The preservice teachers articulated a range of teaching strategies which they used in the development of CT. These mainly included questioning and modelling but they also made use of group discussion, and targeted activities. Questioning emerged as a key strategy (ie, prompting and/or the use of focus questions) in that the preservice teachers consistently emphasised how they had accorded particular attention to the preparation of questions (cf. SM:C13/E13/G13/I13). One group stated that they had explicitly planned a set of questions (see Figure 4) in advance to guide the children 'to think algorithmically and to in turn, debug the programming' (PST#10).

Other strategies included modelling, whole class discussion, discussion of problems in non-technical terms before introducing the technical language, and the use of targeted activities (cf. SM:C15/E15/G15/I15).

The design of the learning environment and CT

The second theme focuses on preservice teacher perception of the design of the learning environment within the specialism and how it contributed to their learning. Three main findings emerged; first, the developmental, progressive and experiential nature of the specialism gradually deepened their knowledge, second the immersive classroom experience 'brought the theory to life', and third, the research element of the classroom experience both heightened preservice teachers' understandings of CT and constructionism and helped to bridge the theory/practice gap (cf. Table S2).

Developmental progressive and experiential nature of the specialism

In each of the focus group interviews, the preservice teachers asserted that the 'structure' or design of the specialism worked to gradually deepen and expand their understanding of CT. In the early modules, they believed that they were 'exploring the components' before moving on to apply this knowledge with Scratch and the Lego WeDo materials and then, later with the children in the classroom experience (cf. SM:C21/E21).

> **...As a result of this, we wanted to try ensure to focus on the development of decomposition during the activities in the second week. Within the race car challenge, we set the children the task of identifying individual features of the race cars they had constructed and altering them to try to have the optimum design and win the race. By doing this, the girls were prompted to look at their design and code according to individual parts of their constructions. Some groups began by focusing on the wheels and looking at how changes to the wheels would alter the speed. Decomposition is occurring here as instead of looking at their model as a whole they were decomposing the problem and focusing on one element. The same can be said in relation to the code, through questioning and scaffolding (where required), we encouraged the children to think about what each block of code was for and if a problem within the code was met how they could break it down using their decomposition skills through debugging.**

FIGURE 3 Extract from Essay of PST#10

We realised that we needed to work on our questioning to get the children to think algorithmically and to in turn, debug the programming. Consequently, we incorporated sets of questions into lessons 2 & 3.

- What do each of the blocks mean in your coding?
- What do you think the display block means?
- What does magnitude mean?
- Which building do you think is more resistant to earthquakes? Why?
- How could you alter those buildings to make them robust?
- Which building fell first? Why?
- Why do you think the tall building was less resistant to the earthquake?
- How did you adapt your buildings? Why?
- What do you now know about the robust structures?
- How do you know this?

FIGURE 4 Extract from essay of PST#10 illustrating questions developed by the group

The experiential nature of the specialism also emerged as significant. The preservice teachers explicitly articulated how the pedagogical approaches they experienced during workshops informed the pedagogical approaches they subsequently used as part of their classroom experience (also cf. SM:C23).

> …we took from what XXX and you were doing with us and applied that… suppose the sort of scaffolding of the tasks and thinking about how to go about solving it, like the questions, the probing questions and the scaffolding that you were doing, for the different tasks and applying that. (FocusGroup#5)

Importance of the classroom experience

The importance of the classroom experience towards deepening understanding of CT and constructionism was one of the key findings. It was strongly emphasised by all preservices that the experience of working with children not only brought the theory 'to life' but helped them to deepen their personal understandings. Specifically, it led them to reflect more deeply on the fundamentals of CT and constructionism as well as develop their understandings of what CT looks like 'in action' (also cf. SM:E25).

> … I found that this [classroom experience] was a most beneficial experience. As part of our major specialism we have focused on constructionism and CT and we have engaged with the LEGO materials … Therefore, for me it was an insightful experience and an opportunity to put my learning into practice and to understand from a teacher's perspective how children engage with the materials. … I learned so much from this experience in both my teaching methodologies and in my own learning. I now have a greater understanding of CT from the perspective of designing learning activities to develop these skills and from observing the children engaging in the activities and seeing first hand CT skills being developed from week to week. (PST#24)

Bridging theory and practice

Finally, the preservice teachers signalled the role of the research they had carried out as part of the classroom experience as critical towards bridging the theory/practice gap. Specifically, they cited analysis of the data they had collected as being instrumental in helping them to further refine and deepen their personal understandings of CT (also cf. SM:C28).

> During the course of this research project, I have learned a lot about computational thinking and constructionism that I could not have learned through doing desk-based research on the topics. This has been a very reflective process in which I have considered my own experiences as well as learning from the pupil's experiences. (PST40)

DISCUSSION AND CONCLUSIONS

The aim of research reported in this paper was twofold; it sought to investigate preservice teachers' understandings of CT on completion of a specialism in digital learning and how the design of the specialism helped to develop their understandings. Findings highlighted strong understandings of CT and some understanding of the interrelationship between the components of CT among the preservice teachers, who were also able to make connections between constructionism and the development of CT. Specifically, many of the preservice teachers identified that the ability to manipulate the objects created supported the development of concrete ways of developing CT (ie, 'objects to think with'). They also demonstrated a high level of pedagogical knowledge, indicating that they clearly understood why they designed particular challenges for the children as part of their classroom experience. This entailed the identification of gaps in the children's knowledge of CT, the use of targeted activities as well as the utilisation of teaching strategies. The design of the specialism was found to contribute to the preservice teachers' deepened understandings in three ways; first, the developmental, progressive and experiential nature of the specialism gradually deepened their knowledge, second, the immersive classroom experience 'brought the theory to life' and third, the research element of the classroom experience both heightened the preservice teachers' understandings of CT and constructionism and helped to bridge the theory/practice gap.

Findings from our study suggest that the preservice teachers are beginning their careers with robust understandings of the 'what' and the 'how' of CT. So rather than having an abstract definition and understanding of CT which is not incorporated into their teaching, the beliefs and knowledge of these preservice teachers are interconnected with their practice (Clarke & Hollingsworth, 2002) and they have developed a robust understanding of 'how CT is relevant to their existing practice' (Ketelhut et al., 2020, p. 174). This is not to suggest that their learning is complete but rather that it is a starting point of the development of their pedagogical knowledge relating to classroom content and practice in CT. Although these preservice teachers have been introduced to CT concepts early (Yadav et al., 2014), it is imperative that structures are put in place to support them to continue learning in their teaching careers.

These findings also warrant further comment in relation to the design of the specialism. In contrast to previous studies where efforts to expose preservice teachers to CT have focused on its introduction in existing modules in teacher education programmes (Adler & Kim, 2018; Bean et al., 2015; Chang & Peterson, 2018; Jaipal-Jamani & Angeli, 2017; Yadav et al., 2014; Zha et al., 2020), the specialism in digital learning is a discrete element of the BEd programme comprising four modules or 20 ECTS credits. As a consequence, this enabled us course designers to provide an immersive experience for the preservice teachers. Over the duration of the specialism, they were immersed in a range of different and progressively more challenging learning tasks in which they used a range of expressive computational materials, were given the time to 'play', to get to know themselves as learners, to think, reflect and to develop an awareness and appreciation of CT. They were also provided with the opportunity to put their new understandings into practice in a classroom while we, as their teachers, continuously worked alongside them to guide and provide feedback. These facets of the specialism are significant in two ways. First, they strongly align with the features of effective teacher learning as outlined by Darling-Hammond et al. (2017) ie, that teacher learning should be of sustained duration, allowing time to grapple with concepts, try out new learning in the classroom, reflect on practice and receive feedback. In addition, and reflective of the constructionist underpinnings of the specialism, the preservice teachers were guided to use their own pedagogical practice as 'an object-to-think-with', thus enabling them both to externalise and examine their understandings of CT and to experiment with their pedagogical practice.

Our findings also have important implications for how to embed the development of CT within teacher preparation programmes. What this study highlights is the value of incorporating an immersive model of developing CT that is embedded within the context of the curriculum they teach and that spans the entire teacher preparation programme. In addition, exposure to CT should not be confined to those preservice teachers who opt to take specialisms in digital learning; rather it should be a core element of teacher preparation as without this, there cannot be a system wide embedding of CT within the curriculum. In the Irish context, there are signs of hope in this regard. The recently published Primary Curriculum Framework (NCCA, 2020) positions CT as essential for all primary school children. The hope is that this framework in combination with the Digital Strategy for Schools (DES, 2015) and the latest Teaching Council requirements which acknowledges the role of teacher preparation (Ceim, 2020) will be the catalyst to fuel systematic change regarding CT.

Finally, while insights gained from this study are relevant for the design of teacher preparation programmes, there are other factors to be considered such as the dispositions of preservice teachers, time and scalability. Barr and Stephenson (2011) assert student attitudes as a critical factor of engaging in CT. In this study, the preservice teachers had elected to partake in the major specialism and so, it could be argued that their dispositions towards using digital technologies in classroom are positive. It thus leads to the question of how the dispositions of preservice teachers should be taken into account when further developing this model of preservice teacher education. It also draws attention to the challenge of scaling the model. For example, in our case, to include not only those preservice teachers taking the specialism in digital learning but the larger cohort of BEd students (450 students per year group).

To conclude, we stress the need to build an understanding of CT as a way of thinking and a way of learning embedded in classroom practice. For if teachers are to transform classroom practice to embed CT, they need to experience challenging immersive learning environments and begin to examine their existing practices in a sustained intervention with the opportunity to reflect and share with others. Otherwise, current forms of practice will not change and we will not ensure that all student have the opportunity to develop CT at primary level. This is increasingly important as the increasing ubiquity of computing creates a demand for a population that can productively engage in CT (Ketelhut et al., 2020). Coupled with this is the recognition that establishing a conceptual understanding of CT and the ability to transfer CT skills across different settings requires prolonged exposure to this mindset (Yadav et al., 2014, 2017) and so should begin at primary level (Barr & Stephenson, 2011; Qualls & Sherrell, 2010). Educating primary school teachers to embed the development of CT within the curriculum increases the chance of reaching all students (Israel et al., 2015) early in their schooling, and not only those who are in schools that can provide standalone computing classes (Yadav et al., 2017).

In most cases, although the experiments have been interesting and exciting, they have failed to make it because they were too primitive. Their computers simply did not have the power needed for the most engaging and shareable kinds of activities. Their visions of how to integrate computational thinking into everyday life was insufficiently developed. But there will be more tries, and more and more. And eventually, somewhere, all the pieces will come together and it will "catch." One can be confident of this because such attempts will not be isolated experiments operated by researchers who may run out of funds or simply become disillusioned and quit. They will be manifestations of a social movement of people interested in personal computation, interested in their own children, and interested in education.

FIGURE 5 Extract from the book Mindstorms, Papert (1980, p. 182) [Colour figure can be viewed at wileyonlinelibrary.com]

We leave the final word to Seymour Papert and his understanding of CT and his belief that it was computing limitations that were holding things back and that eventually the idea of children engaging in CT would 'catch' as there would be 'a social movement of people interested in personal computation … and in education' (Papert, 1980, p. 155) (see Figure 5). The technological advances since 1980 have resulted in the ubiquity of computing devices available for use in schools and the possibility of programming them to represent and understand real-world problems, provide new opportunities for constructionist learning, in particular the development of CT. But key to ensuring that children engaging in CT will 'catch', is the learning environment and the principles underpinning its design.

The authors propose that it is the combination of the choice of particular expressive computational materials and immersion in a learning environment underpinned by constructionist principles that enable the development of CT in primary classrooms. They believe this has been demonstrated in the current study which illustrates how preservice teachers' understandings have developed to the degree that they now appreciate the importance of embedding CT into a way of learning for children. As teachers are the key to children's CT development we now hope that as future teachers our preservice teachers will see CT as 'way of thinking' (about how to build knowledge) and 'a way of working' (about how they design for and engage children in learning environments which develop children's CT).

CONFLICT OF INTEREST

The authors have no potential conflict of interest to disclose in relation to what is presented in this paper.

ETHICS STATEMENT

This research was carried out with full ethical approval from Dublin City University's Research Ethics Committee.

DATA AVAILABILITY STATEMENT

As the authors did not specify sharing the data with anyone but the authors in the original research ethics application submitted to Dublin City University's Research Ethics Committee, unfortunately the data set cannot be accessed by anyone other than the authors.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the Supporting Information section.

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