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Digital Competence & Computational Thinking for Preschool Pre-service Teachers: From Lab to Practice

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ABSTRACT
Digital competence is a skill associated with the 21-century abilities essential to contribute to today's and tomorrow's digital and technical environments. Computational Thinking (CT), which is a thought process for problem-solving, is one of the emerging trends that makes up digital competence. In our explorative study, we have used educational robotics with four pre-service teachers during their four-weeks placement at different preschools. We applied three distinct and complementary approaches to design and conduct this study: Systems Thinking (ST); Technological Pedagogical Content Knowledge; and Computing Pedagogy. Our findings are categorized in two main perspectives: pre-service teachers and children. In the pre-service teachers' perspective, the participants indicated that their educational program lacks specific content and activities related to digital competence, CT, and programming. Despite the initial pre-service teachers' thoughts on improvement of children's CT concepts, the findings show that CT practices such as collaboration and trial and error were developed. From the children's perspective, the empirical findings illustrate that digital competence and CT development vary depending on the age of the children; whereas logical thinking and pattern recognition are skills that were present along the whole age range of children (ages 2-6), other CT skills like algorithmic thinking were developed among older children only (aged 5-6). We learned that an ST approach can be helpful, as multiple factors are involved in the practice. It reveals the underlying features of the situation that emerge when components of the system interact with each other.

KEYWORDS
Computational thinking, systems thinking, digital competence, pre-service teacher education

1. INTRODUCTION
The so-called 21st century skills are an essential set of skills needed to be a competent citizen in our intensely technological society. To be able to contribute to it, we need to prepare our children to acquire those skills from very early ages. Along with different meta-skills such as problem-solving, collaboration, critical thinking, communication, and creativity, two other core skills make up digital competences, technical and information management (Van Laar et al., 2017). Having these skills means having the technical skills necessary to use digital technology and services and the knowledge necessary to find, analyze and critically evaluate information in different media, that is, media and information literacy. Computational thinking (CT) is a thought process as well as a skill for problem-solving and comprises different concepts and practices. According to Grover and Pea (2018), CT concepts include logical thinking, algorithmic thinking, pattern recognition, abstraction and generalization, evaluation, and automation. Regarding CT practices, they include problem decomposition, creating computational artifacts, testing and debugging, incremental development, collaboration and creativity.

The teaching of programming and CT in STEM related subjects has increased the need for digital competence development for pre-service and in-service teachers (Ottenbreit-Leftwich et al., 2021). The current trend is to teach digital competences to educators, but teacher training programs vary in terms of systematicity and in the various European countries (Bourgeois et al., 2019). However, little is known about an integrated approach for digital competence development for pre-service teachers (Howard et al., 2021), at least in Sweden. Most teacher education programs focus on content knowledge development rather than pedagogical intervention or technology knowledge around CT (Ottenbreit-Leftwich et al., 2021). Even less is known about preschool teachers' perceptions of CT and related professional development of this group of teachers (Papadakis & Kalogiannakis, 2022).

In Sweden, in 2018, the government revised the National School Curriculum with a new general section for compulsory schools emphasizing the importance of digital competences, both for teachers and students. Addressing the digital competences, CT is implicitly incorporated in terms of problem-solving and critical thinking. In fact, as part of the digital strategy of the Swedish National Agency for Education (Skolverket), CT skills are important to improve digital competence (Esteve-Mon et al., 2020). A recent study on 21st century skills from Sweden's pre-service teachers illustrates that digital literacy, critical thinking, and problem-solving are the most important skills they need for future teaching (Karakoyun & Lindberg, 2020). Therefore, this paper describes the different activities and outcomes of an exploratory pilot study named *Visual programming: From lab to VFU in preschool* within the context of a NordPlus funded project– *Digital Competence in Teacher Education in the Nordic Countries* (UIS, 2021). The project aims to establish a Nordic and Baltic network with the goal of promoting theory and practice in teacher education within the framework of digitalization in schools. The explorative study described in this paper took place during the Fall of 2020 and ended in June of 2021 with the participation of four preschool pre-service teachers exploring how to work with educational robotics. The theoretical approach of the study and the analysis of the data are based on the concepts of System

Thinking (ST) as the meta-perspective for designing of the project and evaluation of the findings along with two others, namely Technological Pedagogical Content Knowledge (TPACK) framework and Computing Pedagogy.

The remaining of the paper is structured as follows: first, we describe the methodological approach of our work including the settings, theoretical foundations, and data collection methods. The empirical findings and discussions are then presented based on different data collection methods we used prior to and during the project. Lastly, the concluding remarks are described.

2. METHODOLOGICAL APPROACH

Different activities were conducted, including workshops, hands-on practices, visual programming sessions, and pre-service teachers' supervision both at university and preschools. The main goal of the different activities was to gain knowledge and to give an insight regarding the development of digital competence to the participating pre-service teachers, but also to create a long-term and sustainable collaboration between the research group and the university's teacher training program to further CT development into the program. The settings and participants of the project as well as theoretical frameworks of the study are explained below.

2.1. Settings

Four pre-service teachers (ages 23-32) in their fourth and final year of the preschool teacher program participated in the project during the Spring of 2021 (see Table 1 for details about participants and the children). Two PhD students and one research assistant in cooperation with two professor supervisors planned and designed the activities and guided the participating pre-service teachers through the different activities, as mentioned earlier. The whole internship period was four weeks. Firstly, the pre-service teachers spent two days at their preschool placement to get to know the children and their new colleagues. Then, they participated in 3-day workshops, conducted for 21 hours in total. During the workshops, the students had the chance to get acquainted with educational robotics construction kits that they would be using during their internship at the preschools. Also, the pre-service teachers were introduced to basic programming using a block-based graphical interface, and they planned the work to conduct at their internship placement at the preschools. Meanwhile, we conducted discussions with pre-service teachers to evaluate their understanding and perception of CT. Then, each of them took two sets of construction kits to use with the children. The pre-service teachers would later apply their experience from the workshops at the lab into their internship program in preschools for the remaining three weeks. Throughout the internship, the pre-service teachers shared their experiences and reflections with the rest of the group during three online meetings that were conducted via videoconference at the end of each week. For this project, we used the Engino Robotic Platform (ERP)[1] that includes building parts and visual programming software (KEIRO)[2] with the potential of dynamic construction.

Table 1. Participants Information

Pre-service Teacher ID	Children **Age at Preschool**	**Number of Children**
A	5-6 years old	15
B	2-3 years old	12
C	3-6 years old	16
D	3-5 years old	18

2.2. Theoretical Foundations

This explorative study was carried out based on the application of three distinct and complementary theoretical frameworks: ST, TPACK, and computing pedagogy.

Considering different factors involved in our study such as study objectives, pre-service teachers' background in terms of digital competence, and students with varying ranges of age, we perceived the situation as a system of integrated elements that needed a systems approach. So, we took the ST lens as one of the main theoretical frameworks for this study. ST helps us perceive the big picture, the boundaries, perspectives, and the relationships within the systems we work in (Cabrera & Cabrera, 2019). It plays a essential role in our approach, considering two points. Firstly, and from a broader perspective, ST leads towards the sustainable development of the educational context by taking an integrated holistic approach based on multi-stakeholder perspectives (Reynolds et al., 2018), which is aligned with the definition of the digital competence defined by Skolverket on critical and responsible usage of digital tools and resources (Feriver et al., 2019; Skolverket, 2021). Secondly, it helps to improve critical thinking and problem-solving abilities in complex settings through developing the metacognition skills of learners (Cabrera & Cabrera, 2019). A four-component ST model adapted from Cabrera & Cabrera (2019) is used for pre-service teachers' training. The model named *ST loop* includes plan and design based on our previous experiences (mental model), workshop training (approximation), practice in preschool (real world system), and feedback collection (information). This loop model guided our project and builds up our future research.

The TPACK framework (Mishra and Koehler, 2006) guided us in the training of the pre-service teachers during the workshops. Referring to the shortage in studies that focus on pedagogical aspects of pre-service teachers' CT development (Ottenbreit-Leftwich et al., 2021), we focused on pedagogical content knowledge (PCK) as well as technological content knowledge (TCK) of the TPACK model. As seen in Figure 1, CK presents digital competence and CT in our study. TCK refers to ERP sets and their programming software (Keiro) and PCK is applied through maker activities and storytelling.

[1] https://www.engino.com/w/

[2] https://enginoeducation.com/downloads/

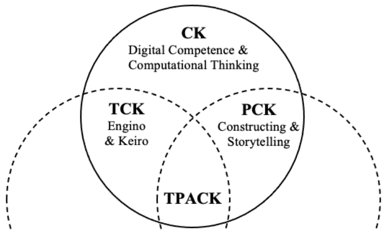

Figure 1. Applied TPACK framework

We have also followed a computing pedagogy model consisting of four implication's elements: approach, context, programming language, and engagement (Beauchamp, 2016; O'kane, 2019). It helped us design our activities in a way to maximize participants' engagement by engaging participants in making creative activities that are open-ended.

2.3. Data Collection Methods

We applied three data collection methods in our study: pre-questionnaire, interviews, and portfolios.

A pre-questionnaire was filled out online before starting the workshops. The goal of this survey was to get information about pre-service teachers' previous knowledge and experience on digital competence and CT. From the ST perspective, teachers are considered as important stakeholders throughout the design of our activities. In addition, looking at the part-whole notion in systems approaches (Cabrera & Cabrera, 2019), the pre-questionnaire gave us a view on constraints and issues (as parts) within the teacher program system (as a whole) in our study. The questions were designed according to the TPACK model in addition to some questions regarding CT key concepts.

At the end of each one of the four weeks of internships, we had meetings via videoconference to hear about the pre-service teachers' experiences and feedback using the ERP sets with the children at the preschools and to provide them with personal feedback. Feedback is an essential factor in any systems approach considering that different people have different priorities (Reynolds & Holwell, 2020). It is important to keep in mind that the four volunteers participating in this project worked with children of different ages, ranging from 2 to 6, and thus their children's cognitive development was quite diverse.

The pre-service teachers were expected to make individual reports of their weekly activities in the form of a *portfolio*. They were asked to include a description of their activities in the preschools, their own and children's experience around ERP and programming, and their achievements throughout the conduction of the different activities with the children. Students complemented the portfolios with pictures. Pre-service teachers who worked with younger children were suggested to focus on implementing CT concepts by applying methods based on storytelling. Storytelling method is applied when the concepts, definitions, and conceptualization of the provided contents are complex and could not be understandable for the target group (Wolz et al., 2011). This method is a teaching approach with the potential of creating and improving emotional intelligence to give children an insight into human behavior (Miller, 2021).

3. EMPIRICAL FINDINGS

According to the pre-service teachers' responses, digital technologies have not been properly introduced in their teacher program and there is insufficient specific education in the field of digital competence and programming for preschool teachers. Accordingly, this represented a considerable limitation when they were trying to apply digital tools and applications in their current programs' syllabus. Moreover, although the notion of digital competence is occasionally mentioned in their syllabus, the preschools' curriculum lacks sufficient content in connection to digital competence, CT, and programming. Our initial discussions with pre-service teachers in the first three days of the workshops suggest that the notion of CT was quite new to them. So, to evaluate pre-service teachers understanding of CT elements, we asked them to sort a few of the main CT concepts in order of importance related to children. Their responses showed that, in their view, logical thinking is the most important element of CT, then pattern recognition, abstraction, generalization, and lastly, algorithmic thinking. In addition, according to the pre-service teachers' responses, two concepts of CT, namely automation and evaluation, were the least important for children at the preschool level.

According to the interviews with the pre-service teachers when they had their internship with the children, they reflected on different aspects related to CT. One of the pre-service teachers who worked with children aged 3-6 reflected that the children of this age group can recognize patterns and follow instructions. The pre-service teacher pointed out that some of the children could figure out what the next steps were supposed to be. In addition, only one of the pre-service teachers managed to successfully make the children design simple codes, as these children were 5 to 6 years old. The other three pre-service teachers, whose children were younger (aged 2 to 4), mentioned that they had no expectations to do actual programming with children of these ages. Their empirical work with children at preschool revealed that the children were simply not mature enough to be able to understand the underlying concepts required to build an algorithm, and therefore they were not able to make any program. According to the pre-service teachers' reflections, trial and error efforts were common activities that the children did while building their models using ERP. Based on what they observed, the children they worked with applied very often trial and error when learning to join the different building pieces together, and they would engage in modifying the models they had built when they would not serve the purpose they had in mind.

Three pre-service teachers who worked with older children agreed that the children were able to collaborate with each other and build together. The pre-service teachers also commented that rather frequently, children were willing to help each other and solve problems together. An interesting aspect mentioned was that, in general, children under four years old seemed to have much more difficulties working collaboratively with other children. On the contrary, children aged four and up showed a much better capability to work and build as a team and solve problems together. Pre-service teachers also referred to the concentration span of the children. That is, children sometimes lose focus and concentration during the activities.

The observations from the materials shown in the portfolios demonstrate that the children's skill levels and interests were different in terms of getting familiar with digital tools. Pre-service teachers believed that it was a worthy challenge when the children are trying to control the devices with mobile phones or tablets (see Figure 2). One pre-service teacher explained that it was important to let students think out-of-the-box so that they could build their own robots and follow their own plans.

Figure 2. Controlling robots with a mobile /tablet

Pre-service teachers observed that children of age 5-6 tried to solve the problems by getting help from each other rather than asking the teacher. They mentioned that in general, the children were more motivated to build freely rather than building by following instructions. In addition, children wanted to build their own imaginary models and they collaboratively tried to figure out which components would have been suitable for their selected models such as a train. Based on collected content of the pre-service teachers' portfolios, the development of CT skills was observed when the children were trying to solve a common problem by using different components, changing the general structure, and modifying them based on their own imaginary stories. For example, as seen in Figure 3, the children imagined and discussed a familiar story about how they might make a train to carry their animal dolls on it. It is worth mentioning that children applied their previous experiences when they played with ERP sets. For instance, when assembling the ERP blocks, the children showed skills that were not demonstrated particularly when compared with playing with Legos' materials, which they had previously tried, according to the portfolios.

Figure 3. Redesigning the story and building a train

The pre-service teachers believed, according to the portfolios, that more teaching is required, having a special focus on more practical-oriented activities to improve pre-service teachers' learnings and skills. According to them, still it needs to be more transparent and specific when teaching each concept of CT. They also stated that the time they spent at the lab for learning and practicing CT concepts prior to their internship was not enough for sufficiently practicing with digital tools. Nevertheless, they expressed that the subjects of the use of digital tools in education and programming are necessary subjects that need to be included as an integral part of their preschool teacher program. The pre-service teachers stated that if their teachers or the people responsible for the teacher program are flexible, they could modify the workshops' plan and adapt it to the context in preschools to improve the teaching of CT.

4. DISCUSSIONS

From the triangulation of data, we learned that an ST perspective can be helpful as multiple factors contribute to the different CT practices. The children's age, the use of mobile devices, building skills, and previous experience of the children are examples of these factors in our study. According to the ST approach, we made a distinction about the results from two main perspectives: the pre-service teachers and the children one. Distinctions and perspectives are considered as two underlying fundamentals of any ST approach (Cabrera & Cabrera, 2018, 2019) and it helps us to frame the results in a simpler fashion.

4.1. Pre-service Teachers' Perspective

From the pre-service teachers' perspective, their educational program needs specific content and activities related to digital competence, CT, and programming. According to Skolverket's digitalization strategy, CT and programming must be integrated into Sweden's national preschools' curriculum (Skolverket, 2021). However, except for one of the participants, the rest of them were all unfamiliar with CT. According to Esteve-Mon et al. (2020), there is a two-way interconnection and a positive correlation between CT and digital competence. While CT builds up and integrates digital competence, students with a better perception of their digital competence gain higher CT skills. The participating pre-service teachers declared that they worked with digital technologies only occasionally during their studies, however, according to pre-questionnaire data, the notion of CT was quite new to them. That is why, improving their CT skills might influence their digital competence development.

Following the CK element of the TPACK model, we attempted to build their CT understanding through lectures and invited them to discuss CT concepts that were more relevant to preschool children. When considering the CT components *concepts* and *practices* (Grover & Pea, 2018), the pre-service teachers' initial perception was that CT concepts could be developed in early-age children. However, the results show that CT practices such as collaboration and trial/error were developed, according to pre-service teachers' observation. In line with Ottenbreit-Leftwich et al. (2021), lack of digital TPK in teacher training programs is another aspect pre-service teachers mentioned in their workshops and interviews. Accordingly, we took advantage of the ERP affordances and storytelling-related activities as well as computing pedagogy approach to develop their TPK. In particular, PCK and TCK are useful to guide pre-service teachers on how to integrate CT in their activities, pedagogically and technologically (Ottenbreit-Leftwich et al., 2021). Regarding TCK, the existence of physical and virtual maker technologies associated with ERP and Keiro makes it possible to use physical construction for younger children who cannot handle actual coding. With PCK, we suggested digital storytelling by means of ERP to motivate students and engage them with the activity (Beauchamp, 2016; O'kane, 2019).

Storytelling has taken a supplementary role, whereby CT practices and TPACK teaching methodology provide a friendly learning environment. To do so, it needs to focus on the role of educators in terms of providing an interactive communicative learning environment. It is also in line with computing pedagogy approach (O'kane, 2019) we followed to increase the participants' engagement with the activity. As seen in Figure 4, pre-service teachers played different roles in a storytelling activity they carried out together during the workshops.

Figure 4. The practical activity of students playing the role of teacher and children.

4.2. Children's Perspective

Moving around the point from which an object is viewed is an essential characteristic of an ST approach, meaning that an idea can be the point or the view of a perspective (Cabrera & Cabrera, 2018, 2019). To deeply understand the digital competence and CT skills progress, we shift the perspective to children in this section. In other words, children are the lens through which we look at the CT and digital competence. Through the collected portfolios we could discern that pre-service teachers' work with the children was experienced differently depending on the children's age. Whereas logical thinking and pattern recognition are skills that were present along the whole age range of the children (ages 2-6), other CT skills, such as algorithmic thinking, were demonstrated and developed among older children only (ages 5-6). When younger children (ages 2-3) could not do actual programming, their CT skills could be detected and improved while participating in maker activities, controlling the robots using mobile devices (as a remote control), and using physical buttons to run the motors (see Figure 2). Giving the children simple guidelines and letting them try to figure out, for instance, how they can control their robots to reach a given goal is considered a way to introduce CT to young children (Papadakis & Kalogiannakis, 2022). This pattern was quite similar for the pre-service teachers who worked with the younger children. When it comes to coding activities of children aged 5-6, although they used simple functions to make a short program algorithm, it is very fascinating in terms of implementing the fundamental programming practices in this age group.

ERP provides an application for mobile devices and tablets that allow the user to control the robots by tilting the mobile phone, thus serving as a sort of remote control. This function helps the more curious children wanting to try to logically control the robots they built. The multifunctional potential of the robotic platform and the computing pedagogy approach we used in our study enables us to move around the TPACK framework from TCK to PCK (and vice versa) when pre-service teachers encounter limits according to children's ages. Except for one group of children (2-3 years old), the pre-service teachers observed that trial and error was the common CT practice among all children, leading to improvements during the construction process of the ERP. Many of the modifications of the constructions were made solely based on the ingenuity and creativity of the children. According to Grover and Pea (2018), trial and error reflects incremental development of students that is categorized under CT practices. The collaborative and communication skills, as well as a cognitive development associated with the ability to follow instructions among the children, are some aspects that show improvement by conducting activities of building with the ERP construction sets.

Considering storytelling as an interactive teaching method for children, following the patterns and scenarios while playing would be much easier than applying traditional teaching methods such as describing instruction and explaining concepts. This approach also gives children a chance to think outside-the-box with the potential of creating and improving emotional intelligence and provide support (Miller, 2021). The example illustrated in Figure 3, would be a kind of fully functional play story that provides an interactive educational environment where children come up with their own design strategy. That is like redesigning a story plan, but this time, it is made by the children's innovative thinking.

According to Reynolds and Holwell (2020), ST reveals the underlying features of the situation. For example, when pre-service teachers referred to the loss of concentration when younger children were participating in the building activities for more than 40 minutes, illustrating the importance of time management when working with children of this age.

5. CONCLUDING REMARKS

Currently, the development of digital competence through the integration of CT in formal and informal education is a growing trend in Europe and other regions of the world. In this pilot study, the researchers promote the development of digital competence and CT in preschool teacher education by using the Engino ERP construction kit.

Our findings indicate that there is a lack of professional development in preschool teacher education in terms of digital competences and CT. Integrating CT practices into an educational context would be a positive pedagogical and computational approach, where children are allowed to test, redesign play, change instructions, and decide whether to collaborate with peers. However, to improve CT skills, we need an ST approach and TPACK methodology as infrastructural development to both empower teachers as well as to provide a feasible CT learning environment in schools. Complementary methods of ST, CK, PCK, and TCK can be an effective approach to deal with very young children in terms of CT development. That is, when one approach is not possible to be applied due to the cognitive level of the young children, it can be supplemented with other methods. Our findings illustrate that not only CT practices are more developed than CT concepts for children aged 2-6, but CT development also vary depending on the age of the children. Whereas logical thinking and pattern recognition are skills that were present along with the whole age range of students, other CT skills like algorithmic thinking were developed among older children only.

Lastly, there is room for improvement in future activities in terms of bringing changes to the preschool curriculum and difficulties related to the Engino building and assembling system for preschool children as these building sets might not be the most suitable when working with children at a preschool level. Looking at the results of this paper on improvement of children's CT practices, more studies are needed to explore how to develop CT concepts.

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