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What Are The Barriers To Teaching Computational Thinking?

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Abstract: Computers were popularized about 40 years ago in the ’80s and the internet 20 years ago in the early 2000s, but the consistent implementation of computer science (CS) is still in early stages in many primary and middle schools (Eickelmann and Vennemann 2017, 733-761). National curricula include computational thinking (CT) and information and communication technology (ICT), but only a few have practical implementation guidelines for them (Bourgeois, Birch, and Davydovskaia 2019). The digital transformation taking place everywhere and in every work area requires new competencies for everyone (Sousa and Rocha 2019, 327-334). The sooner schools adapt to the demand for new skills, the better.

For middle school students to understand and learn programming logic, primary and elementary schools should first teach computational thinking and other basic skills. The National curricula of every country under the scope of this research mention ICT, CS and CT (Bourgeois, Birch, and Davydovskaia 2019), but the content and implementation is left for teachers to decide according to the interviewees in this study (Finland, Estonia, Germany, and Greece, ten teachers each). Without unambiguous definitions and guidelines, implementation varies a lot between schools and even between teachers. For example, in the Estonian curriculum, digital competence is one of the mandatory general competencies that schools must develop in the pupils (Lauringson and Rillo 2015). However, most interviewed Estonian teachers say that in order to carry this out, they need more allocated time, resources, and teacher education.

This study aims to understand the most common barriers to teaching computational thinking in Europe. A total of 41 teachers from four different countries were interviewed about teaching CT and other computer skills. The most common barriers found in all countries were lack of time, lack of teacher education, lack of material, and lack of resources. Student motivation and student skill heterogeneity were among the new barriers found. The results vary between countries.

Keywords: Computational Thinking, Barriers, Teaching, Curriculum, Competences, Technology, Education

Suomenkielinen tiivistelmä: Tietokoneet ja tietotekniikka yleistyivät noin 40 vuotta sitten 80-luvulla ja internet yli 20 vuotta sitten 2000-luvun alussa, mutta tietojenkäsittelytieteen (CS) johdonmukainen toteutus on edelleen alkuvaiheessa monien maiden ala- ja yläkouluissa (Eickelmann and Vennemann 2017, 733-761). Kansalliset opetussuunnitelmat sisältävät ohjelmallisen (algoritmisen) ajattelun (CT) sekä tieto- ja viestintätekniikan (ICT) osaamisen, mutta vain harvoissa opetussuunnitelmissa on käytännön toteutusohjeita (Bourgeois, Birch, and Davydovskaia 2019). Digitaalinen muutos, joka tapahtuu kaikkialla ja kaikilla aloilla, vaatii uusia taitoja kaikille tämän hetken ja varsinkin tulevaisuuden työntekijöille (Sousa and Rocha 2019, 327-334). Mitä nopeammin koulut sopeutuvat uusien taitojen tarpeeseen, sitä parempi.

Jotta yläasteen oppilaat ymmärtäisivät ja oppisivat ohjelmoinnin ja tietokoneiden logiikan, esi- ja ala-asteen koulujen tulisi ensin opettaa ohjelmallista ajattelua ja muita perustaitoja. Jokaisen tämän tutkimuksen piiriin kuuluvan maan kansallisissa opetussuunnitelmissa mainitaan ICT, CS ja CT (Bourgeois, Birch, and Davydovskaia 2019), mutta sisältö ja toteutus jätetään tämän tutkimuksen haastateltavien mukaan opettajien päätettäväksi (Suomi, Viro, Saksa ja Kreikka). Ilman yksiselitteisiä määritelmiä ja suuntaviivoja toteutus vaihtelee paljon koulujen ja jopa yksittäisten opettajien välillä. Esimerkiksi Viron opetussuunnitelmassa digitaaliset taidot on yksi pakollisista yleisistä taidoista, joita koulujen on opetettava oppilaille (Lauringson and Rillo 2015). Useimmat haastatellut virolaiset opettajat sanovat kuitenkin, että tämän toteuttamiseksi he tarvitsevat enemmän varattua aikaa, resursseja ja opettajankoulutusta.

Tämän tutkimuksen tarkoituksena on ymmärtää yleisimmät esteet ohjelmallisen ajattelun opettamiselle Euroopassa. Yhteensä 41 opettajaa neljästä eri maasta haastateltiin CT:n ja muun tietotekniikan opettamisesta. Kaikissa maissa yleisimpiä esteitä olivat ajanpuute, opettajien koulutuksen puute, materiaalien puute ja resurssien puute. Oppilaiden motivaation puute ja erot taitotasoissa ovat muutamia tässä työssä löydettyjä esteitä. Tulokset vaihtelevat jonkin verran maittain.

Avainsanat: Ohjelmallinen ajattelu, esteet, opettaminen, opetussuunnitelma, kompetenssit, teknologia

Glossary

CS	Computer science
STEM	Science, Technology, engineering and mathematics
CT	Computational thinking
ICT	Information and communication technology
AT	Algorithmic thinking
ISTE	International Society for Technology in Education
CSTA	Computer Science Teachers Association
K-12	An American expression that indicates the range of years of publicly supported primary and secondary education
UK	United Kingdom
FNCC	Finnish National Core Curricula
MAOL	Association of Teachers of Mathematical Subjects, Matemaattisten aineiden opettajien liitto
Becta	British Educational Communications and Technology Agency
TAM	Technology Acceptance Model
SMK	Subject matter knowledge
ICILS	International computer and information literacy study
COTA	Computational thinking and acting -project
HITSA	Estonian Information Technology Foundation for Education, Hariduse infotehnoologia sihtasutus

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1 Introduction

Computational Thinking (CT) is a set of competencies and skills needed to work and advance in the current world of technology. A basic understanding of computer program logic and the type of problems computers can solve effectively is critical for the future workforce. Education of students on CT is essential for the whole economy, when everyone can understand the basics, the easier it is to develop more effective software, and users can give more helpful feedback for the developers.

Computers were popularized about 40 years ago in the ’80s and the internet 20 years ago in the early 2000s, but the consistent implementation of computer science (CS) is still in its early stages in many primary and middle schools (Eickelmann and Vennemann 2017, 733-761). National curricula discuss information and communication technology (ICT), but only a few introduce practical and imperative implementation guidelines (Bourgeois, Birch, and Davydovskaia 2019). The digital transformation taking place everywhere and in every work area requires new competencies for everyone (Sousa and Rocha 2019, 327-334). Students will need new competencies throughout their school and working life. CT is mentioned in school curricula around Europe, but the implementation varies even inside schools. The material points out the teachers’ activity as a primary driver of CT teaching.

For middle school students to understand and learn programming logic, preliminary and elementary schools should first teach computational thinking and other basic skills. The national curricula of all the countries under the scope of this research mention ICT, CS, Algorithmic thinking (AT), and computational thinking (CT) (Bourgeois, Birch, and Davydovskaia 2019), however, CT has been a relatively new addition, and schools are lacking both materials and pedagogical models to teach CT in the classrooms. Schools adopting the new curricula face various barriers when teaching CT.

This study aims to map out the most common obstacles to teaching CT. Research questions are “What are the current barriers to teaching computational thinking?” and “How can these barriers be, or have been, overcome?”

The study aims to determine the main barriers to teaching computational thinking and other related skills to primary school grades 3-6 in 2020. This study reviews the literature to define “Computational Thinking” and categorizes possible barriers to teaching CT. A literature review was performed to create a framework of common barriers in teaching CT and ICT. The study was designed as a descriptive face-to-face interview study with teachers who have knowledge and experience about the teaching of CT. A questionnaire with open questions was formed, and 41 teachers from four different countries (Estonia, Finland, Germany, and Greece) were interviewed about their own and their national teaching of CT. Participants were chosen as a convenience sampling and are active CT teachers. The answers were compared to the framework, and the framework complemented. Common obstacles tend to be outdated computers, lack of resources, lack of education, and lack of time.

This study is structured as follows. The introduction is followed by Background, chapter 2, where necessary information is presented and published studies used to form a framework of present knowledge. Also, the CT in studied countries' curricula is shortly presented. In chapter 3, Methodology, the design, execution, and analysis of the study are discussed. Chapter 4, Results, presents the interviewee data, collated data, and also data and comments on each barrier and intervention found. Chapter 5, Discussion, strives to extract new data and to explain the findings. Also, recommendations and good practices for teaching CT are collected there. Chapter 6, Conclusions, concludes and summarizes the study. Also, critique towards the study is gathered in this chapter.

2 Background

2.1 Definition of Computational thinking

In this chapter, CT is opened up as a term.

Computational Thinking can be thought of as a part of information and communication technology, and it is vital to understand their difference. ICT refers to technology and devices used in the context of education. The CT concept was initially introduced by Papert (Papert 1980) and his idea of teaching computing skills to children.

The current use of the term CT was strongly influenced by Wing (Wing 2006, 33-35), who defined Computational Thinking as an "approach to solving problems, designing systems and understanding human behavior by drawing on the concepts fundamental to computer science." A shorter definition is given by Berland and Wilensky (Berland and Wilensky 2015, 628-647) as "the ability to think with the computer-as-tool." While there is no consensus on the definition, we use the following definition: "The ability to understand and utilize information and communication technologies and their key concepts, methods, and tools to solve real-world problems purposefully" (Pawlowski et al. 2020).

The key competencies, according to the International Society for Technology in Education (ISTE) and Computer Science Teachers Association (CSTA), are "Formulating problems in a way that enables us to use a computer and other tools to help solve them. Organizing and analyzing data logically, representing data through abstractions, such as models and simulations, and automating solutions through algorithmic thinking (a series of ordered steps). Identifying, analyzing, and implementing possible solutions to achieve the most efficient and effective combination of steps and resources. Generalizing and transferring this problem-solving process to a wide variety of problems." (ISTE and CSTA 2011)

Wing (Wing 2008, 3717-3725) described that "Computational thinking is a kind of analytical thinking. It shares mathematical thinking in the general ways in which we might approach solving a problem. It shares with engineering thinking in the general ways in which we might approach designing and evaluating a large, complex system that operates within the constraints of the real world. It shares with scientific thinking the general ways in which we might approach understanding computability, intelligence, the mind, and human behavior."

Grover and Pea (Grover and Pea 2013, 38-43) describe the following competencies as being typical for curriculum development in the K-12 context: "Abstractions and pattern generalizations (including models and simulations); Systematic processing of information; Symbol systems and representations; Algorithmic notions of the flow of control; Structured problem decomposition (modularizing); Iterative, recursive, and parallel thinking; Conditional logic; Efficiency and performance constraints; Debugging and systematic error detection."

Programming is not a necessary part of teaching computational thinking, as it can be learned through play and other activities that do not include computers. Some approaches, such as visual programming languages (Grover and Pea 2013, 38-43), integrate programming into CT. At least, the long-term intention of most approaches is that children learn programming languages and, more importantly, think about problems in a way that a programmer would. Even if they were not to program themselves, they learn what kind of problems computers understand and can describe problems they face with software to programmers later in life.

In its most accessible form, computational thinking can be seen as disassembling problems into simple steps that are executed sequentially. A higher understanding of computing is needed to teach abstractions such as stacks, parallel computing, or interleaving algorithms. (Wing 2008, 3717-3725)

Aho (Aho 2011) wrote that computational thinking is the thought processes involved in formulating problems so their solutions can be represented as computational steps and algorithms. Tsarava et al. (Tsarava et al. 2017, 687-695) created a diagram that shows the confluence between coding concepts, CT processes and disciplines they are associated to. (Figure 1)

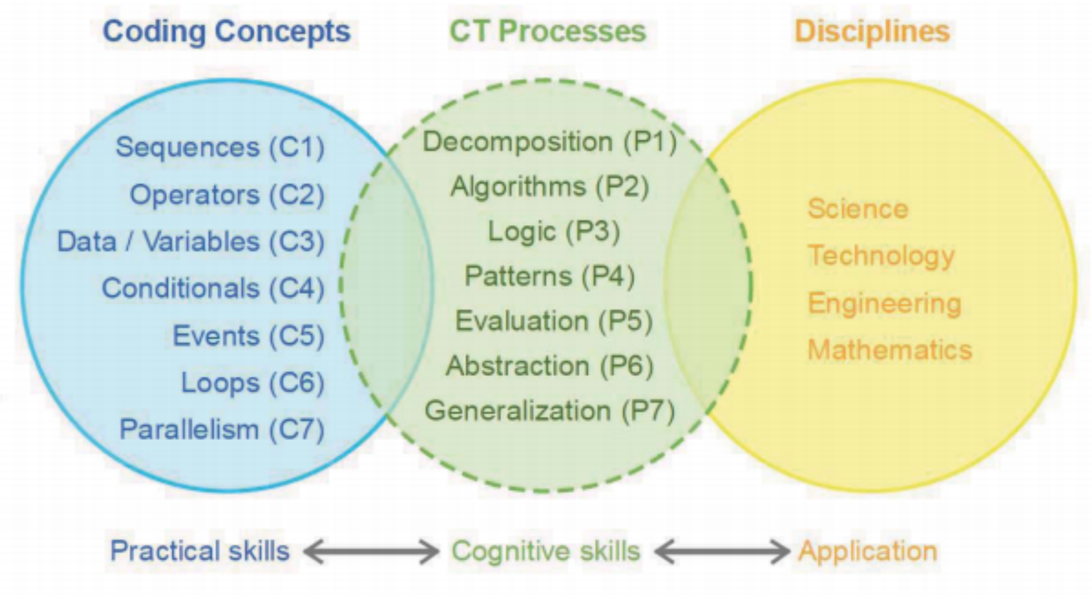

Figure 1. Illustration of association between the practical skill of coding. CT as corresponding cognitive skills and the broad applicability of CT as a general problem-solving strategy to different content domains such as STEM. (Tsarava et al. 2017, 687-695)

In their survey, Balanskat & Engelhardt (Balanskat and Engelhardt 2014) showed that most European countries are already incorporating or are planning to incorporate CT into their K-12 education curricula. For example, the UK has already implemented a complete set of CT courses in all disciplines (Brown et al. 2014, 1-22).

2.2 Teaching CT

Teaching CT skills means teaching students to think like a programmer (Curzon et al. 2014). Teaching CT means teaching aspects like algorithmic thinking, abstraction, generalization, disassembling problems to smaller tasks, and understanding what kinds of commands computers understand (Selby and Woollard 2013). Teaching these skills can be done by playing, acting out different scenarios, and in various other ways not involving computers. A common way to teach about abstractions is by using metaphors. For example, a variable can be seen as a box. The variable's name can be written on the top of the box, so it is easy to refer to. Anything can be put inside the box, numbers, words, or even other boxes. After that, the variable can be used in math, in sentences, and in any other way wanted, just by referring to it with the name on the box. According to Angeli (Angeli and Giannakos 2020, 106185), metaphors are essential and should be constantly developed. Disassembling problems and debugging can be taught, such as giving each other written instructions on how to get from point A to point B in a classroom. The instructions have to take tables and chairs into account and stride length and other possible variants.

In this study, Estonia, Finland, Germany, and Greece were emphasized, and the curricula of these countries are taken into closer scrutiny.

2.2.1 Estonia

The Estonian national curriculum consists of a general part and appendices. The appendices provide subject area plans, elective subject curricula, and descriptions of cross-topics. The national curriculum gives requirements students need to meet by the end of every school level. It is up to schools to design detailed curricula and ways to reach the goal. ICT curriculum/informatics is an elective subject for schools and starts from the secondary school level. If the term "computational thinking" is not directly mentioned in the curricula, it can be connected/integrated across the curriculum via problem-solving, structuring, and modeling processes, from language lessons to natural sciences and math. (Muilu, Clements et al. 2021)

2.2.2 Finland

In Finland, a curriculum framework is given by the ministry of education (Finnish National Core Curricula, FNCC). On CT and ICT, the curriculum is at a relatively abstract level, and each county is in charge of adapting it to their teaching. As Vitikka et al. (Vitikka, Krokfors, and Hurmerinta 2012, 83-96) described, "In Finland, the national core curriculum is a framework around which local curricula are designed. The national core curriculum contains the objectives and core contents of teaching for all school subjects. FNCC also describes the mission, values, and structure of education." ICT is considered a transversal skill and is integrated into other subjects, but the integration has been criticized as the teacher education and support is not up to date (Bell 2019, 5-6). The current FNCC introduced coding to primary education nationally when the curriculum was enacted in fall 2017. Some schools may have taught CT skills before that, but after 2017 every student should receive coding education in primary school. Coding has been integrated into teaching other subjects, such as mathematics, where algorithmic thinking is taught to pupils. According to the Association of Teachers of Mathematical Subjects (MAOL), students taught in different schools and by different teachers are now receiving unequal education, as the skills and resources are heterogeneous all over Finland. (Bell 2019, 5-6)

Fenyvesi et al. (Fenyvesi et al. 2021) have made a descriptive keyword analysis of the Finnish curriculum to find which subjects mention keywords linked to CT. They found that most keywords were mentioned in language subjects. Some keywords like "process" are used in multiple meanings. Problem-solving skills are mentioned as part of most subjects. Fenyvesi (Fenyvesi et al. 2021) found that keywords associated with CT were found mainly in languages, mathematics, environmental studies, visual arts, and crafts.

In FNCC, the requirements for grades 1-2 are practicing instructions and learning their connection to programming. It means students are getting acquainted with programming basics such as instructions administration and causal relationships. During grades 3-4, students should gain positive experiences in programming. Students should exercise programming-related thinking skills, such as comparison and classification. In grades 5-6, students should become familiar with a programming environment, for example, in robotics and maker tools developed for programming-related thinking skills like problem-solving and creativity. Students should understand basic programming infrastructures like loops, if-then-else conditions, and logical operations (no, and, or).

Innokas network (Ansolahti and Kukkonen 2013) shares learning scenarios and training. They created a poster where the ICT and CT requirements in the new 2016 curriculum are in a compact model. (Figure 2)

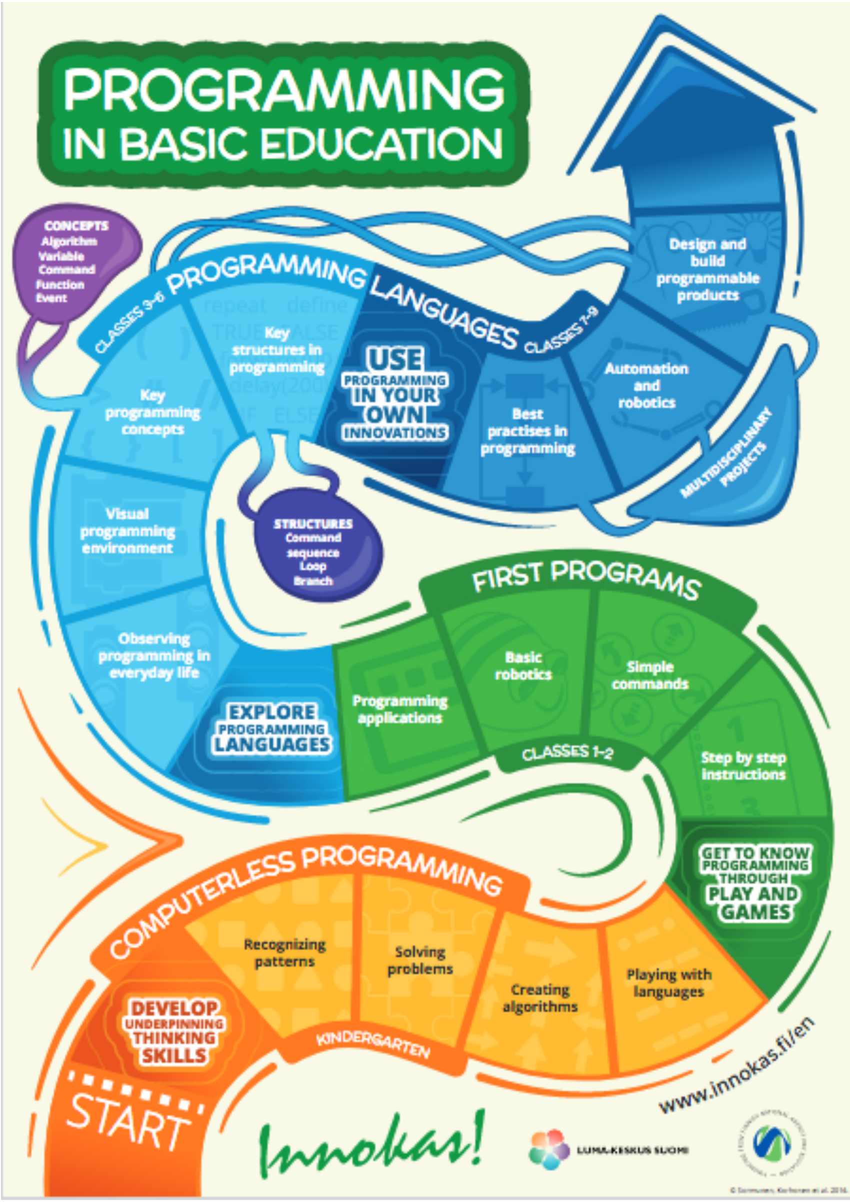

Figure 2. Finnish National Curriculum and the skills taught at every stage of education. (Ansolahti and Kukkonen 2013)

2.2.3 Germany

A curriculum framework is given and organized by states, and the curricula are differentiated by school type. The concept of Computational Thinking is not anchored in the curricula. However, many competencies which are essential to computational thinking are included in different parts of the curricula. Since 2019, a new media concept framework is also part of the curriculum. The new concept is implemented in step with CT and ICT. Students learn skills and use tools that are useful in all contexts. (Muilu et al. 2021)

2.2.4 Greece

Greek curriculum has a part that refers explicitly to computer science. It is important to note that computer science was integrated into the primary school curriculum in 2016 as a one-hour subject per week for all grades. Greece is in a continuous process of embracing new technologies with a primary purpose to get prepared for the digital era. Due to the corona-virus pandemic and the closure of the schools, Greek teachers redefine teaching and learning. They are facing new challenges and are struggling to learn new techno-pedagogies needed to teach online classes. (Muilu et al. 2021)

2.3 Summary of theoretical background: Barriers and interventions to teaching Computational Thinking

2.3.1 Barriers to teaching computational thinking

Computational Thinking will be an essential competency for the next generations. However, a variety of barriers hinder schools and teachers from integrating them into their educational programs. Understanding barriers is the first step to revise curricula and practice.

There are various challenges - or barriers - to introducing computing into primary schools, and they have been categorized in various ways. Generally, there are many barriers to teaching information and communication technologies (ICT) in schools and plenty of ways to classify them. The barriers for teaching CT can be assumed to be at least partially the same as the ones for teaching ICT. Barriers to teaching computational thinking have not yet been widely studied, and this study uses the background of ICT teaching-related barriers and the available studies considering barriers of teaching CT.

Ertmer (Ertmer 1999, 47-61) classified barriers as extrinsic and intrinsic barriers. Extrinsic barriers consist of barriers that are independent of teachers, like lack of resources, lack of time, lack of support from the school, and lack of teacher education. Intrinsic barriers consist of attributes and qualities of teachers, like attitudes, standard practices, and resistance to new technology. Pelgrum (Pelgrum 2001, 163-178) classified barriers as material and immaterial. Material barriers would be, for example, a lack of resources. Non-material barriers are problems with curriculum, such as teacher skill level. According to Bingimlas (Bingimlas 2009, 235-245), British Educational Communications and Technology Agency (Becta, ceased to exist in 2011, and the publications are now unavailable) grouped barriers as school-level and teacher-level barriers similarly to Ertmer (Ertmer 1999, 47-61). Venkatesh & Davis (Venkatesh and Davis 2000, 186-204) developed a Technology Acceptance Model (TAM) to demonstrate variables needed in introducing and deploying new ideas and models. Most barriers listed above can be found in TAM and can be put into hierarchical order.

Bingimlas (Bingimlas 2009, 235-245), Stokke (Stokke 2019), Tedre & Denning (Tedre and Denning 2016, 120-129), and Buabeng-Andoh (Buabeng-Andoh 2012) have gathered categories and types of barriers from literature in the context of teaching ICT and CT. The barriers are divided here into three categories: personal, institutional, and technological factors. (Table x). Categories are not unambiguous and will need further explanation and interpretation in the results and discussion parts of this study.

Barrier themes/categories	**Description**	**Barrier examples**	**References**
Personal Characteristics	Barriers and challenges of individual teachers.	The preparedness, attitudes against CT, lack of competence, lack of confidence, workload	(Schiller 2003) (Russell and Bradley 1997, 17-30) (Bingimlas 2009, 235-245) (Tedre and Denning 2016, 120-129) (Plair 2008, 70-74) (Balanskat 2006) (Buabeng-Andoh 2012)

Institutional Characteristics	Barriers and challenges of institutions and schools	Time given to teachers for teaching CT, lack of educational support, lack of training, lack of leadership support, congested classes, rigid school curriculum	(Vannatta and Nancy 2004, 253-271) (Bingimlas 2009, 235-245) (Anderson and Dexter 2005, 49-82) (Yildirim 2007, 171) (Nikolopoulou and Gialamas 2016, 59-75) (Keong, Horani, and Daniel 2005, 43-51) (Ghavifekr et al. 2016, 38-57) (Hus 2011, 3855-3860)
Technological Characteristics	Lack of devices, equipment, or material	No ready-made material, lack of up-to-date devices, limited access to devices	(Balanskat 2006) (Buabeng-Andoh 2012)

Table 1. Categorization of barriers

Balanskat (Balanskat 2006) and Bingimlas (Bingimlas 2009, 235-245) distinguish teacher-level (e.g., lack of confidence, lack of competence, resistance to change, negative attitudes) and school-level (e.g., lack of time, lack of adequate training, lack of accessibility, lack of technical support) barriers, and divide them to smaller categories. Gillespie (Gillespie 2014) adds more general barriers to this classification, including classroom management difficulties, fear of embarrassment, lack of institutional support, and software and hardware obsolescence. Tedre & Denning (Tedre and Denning 2016, 120-129) recognized risks in teaching CT that even the teacher teaching the subject might not notice, such as focusing too much on CT or forgetting why CT is being taught.

In his article Bingimlas (Bingimlas 2009, 235-245) divided teacher level or personal level barriers to Lack of teacher confidence, lack of teacher competence, resistance to change, and negative attitudes.

Lack of teacher confidence can come from fear of failure (Beggs 2000; Jones 2004), but the causality can also be the other way round (Balanskat 2006). According to Bingimlas (Bingimlas 2009, 235-245), Becta stated, “many teachers who do not consider themselves to be well skilled in using ICT feel anxious about using it in front of a class of children who perhaps know more than they do." Teachers need a constant support person that would be near and readily available to fill in the gaps that arise with technology. (Plair 2008, 70-74)

Lack of competence is directly correlated with the teacher's age (Buabeng-Andoh 2012), indicating the time of graduation and the quality of ICT and CT education the teacher received when studying. Kind (Kind 2009, 1529-1562) found that good subject matter knowledge (SMK) development is crucial for teacher self-confidence tying teachers' competence and teacher confidence together. SMK developed in the teacher education, and trainee phase helps teachers select appropriate instructional strategies and explain phenomena to students. Shulman (Shulman 1986) proposed that teachers have to have good SMK, that they transform to pedagogical content knowledge and transfer their knowledge to their students.

Resistance of change and negative attitude against ICT and teaching CT is well researched (Bingimlas 2009, 235-245) (Jones 2004), but the motives vary. Cox (Cox, Cox, and Preston 2000) found that teachers use new technologies less if they see no need to change their professional practice. Denning (Denning 2017, 33-39) mentioned that teachers are familiar with their original teaching methods, requiring much work to change their teaching materials. They would not resist change but are resisting a new way of doing the same lectures. Schoepp (Schoepp 2005) found that teachers had the technology and the need, but not the education, support, guidance, or reward to take new technology to practice. Even though resistance to change is mentioned often, according to Bingimlas (Bingimlas 2009, 235-245), it seems not to be a barrier itself but is an indication of something else that is wrong. The reasons for resistance to change are difficult to measure.

Barrier	Example	References
Change resistance	Teachers do not want to change the way they are teaching	(Balanskat 2006; Bingimlas 2009, 235-245; Cox, Cox, and Preston 2000; Denning 2017, 33-39; Schoepp 2005)
Lack of teacher education	Teachers do not know how to teach CT effectively. Education would also improve the confidence of teachers.	(Bingimlas 2009, 235-245; Buabeng-Andoh 2012; Ghavifekr et al. 2016, 38-57; Hus 2011, 3855-3860; Keong, Horani, and Daniel 2005, 43-51; Kind 2009, 1529-1562; Shulman 1986; Stokke 2019; Balanskat and Engelhardt 2014)

Teacher motivation	Teachers know how they could teach CT but do not see why they should do it.	(Beggs 2000; Cox, Cox, and Preston 2000; Bingimlas 2009, 235-245; Balanskat 2006)

Table 2. Personal barrier category

Bingimlas (Bingimlas 2009, 235-245) divided school-level barriers into lack of time, lack of adequate training, lack of accessibility, and lack of technical support. Vannatta & Nancy (Vannatta and Nancy 2004, 253-271) show that teachers that have the opportunity to try out technology with their pedagogical approaches are more willing to do it. The opportunity consists of training, demonstrations, opportunities for collaboration, and positive leader. According to Keong, Hus, and Ghavifekr (Hus 2011, 3855-3860; Ghavifekr et al. 2016, 38-57; Keong, Horani, and Daniel 2005, 43-51), lack of time was the most common barrier in including ICT in different subjects. Lack of time can be the time in a tight curriculum or the time for preparing for classes.

Lack of training has also been reported in many studies (Hus 2011, 3855-3860; Ghavifekr et al. 2016, 38-57; Keong, Horani, and Daniel 2005, 43-51; Bingimlas 2009, 235-245; Stokke 2019). This barrier is also similar to the previously mentioned personal barrier lack of competence, but here the responsibility of the lack of competence is transferred to the institute.

Nikopoulou, Keong, Ghavifekr, and Bingimlas (Keong, Horani, and Daniel 2005, 43-51; Bingimlas 2009, 235-245; Ghavifekr et al. 2016, 38-57; Nikolopoulou and Gialamas 2016, 59-75) all mentioned the lack of technical support as a barrier. In some cases, this barrier might be comparable to lack of training, but with ICT equipment, there is always a possibility that some formerly unencountered problem arises. Teachers are not supposed to have the skills of a helpdesk, and their work is supposed to be mainly pedagogical.

Barrier	Example	References
Lack of time	Teachers do not have time to teach CT, among other material, or do not have time to prepare the classes	(Keong, Horani, and Daniel 2005, 43-51; Ghavifekr et al. 2016, 38-57; Hus 2011, 3855-3860; Bingimlas 2009, 235-245; Balanskat 2006)

Group sizes	CT problems need longer attention from teacher per student compared to "traditional subjects," and there is not enough time to attend every student	(Bingimlas 2009, 235-245; Balanskat 2006)
Lack of material	There is no ready material the teachers could use in class.	(Vannatta and Nancy 2004, 253-271)

Table 3. Institutional barrier categories

Lack of accessibility is a barrier that has eased in Europe in the last ten years. (Ayllón et al. 2020) In the international computer and information literacy study (ICILS) (Fraillon and others 2020), the average number of students per digital device (desktop computers, laptops/notebooks, and tablet devices) was reported. The European average is 8.7 students per device. In Finland, an overall average of 3.4 students shares a digital device. Luxembourg (4.5:1), Denmark (4.6:1), and France (7.2:1) are above the European average. Germany is under the average with a ratio of 9.7:1. Italy (14.3:1) and Portugal (16.9:1) have noticeably higher ratios. Other countries in the study were not from Europe.

Barrier	Example	References
Lack of resources	There are often problems with shared computers, such as they are out of battery, need an update, will not find WiFi.	(Ayllón et al. 2020; Balanskat 2006; Bingimlas 2009, 235-245; Ghavifekr et al. 2016, 38-57; Keong, Horani, and Daniel 2005, 43-51; Nikolopoulou and Gialamas 2016, 59-75; Vannatta and Nancy 2004, 253-271; Fraillon and others 2020)

Table 4. Technological barrier category

Tedre & Denning (Tedre and Denning 2016, 120-129) listed risks over CT in their study. They emphasize that CT should be seen as a tool of thinking but not as the only tool. Teachers should keep their eyes open and their ears to the ground to feel how students are receiving each subject. Also, a thinking tool cannot become a skill if it is not used but only taught in theory. To teach CT, a teacher has to know what CT is and what can be achieved with it. Tedre & Denning (Tedre and Denning 2016, 120-129) also wrote that one should not exaggerate the benefits or /and overemphasize CT as a tool. If CT becomes a dogma, students are going to be frustrated and disappointed in one-eyed perspectives. Tedre & Denning and Aho

(Aho 2011; Tedre and Denning 2016, 120-129) emphasize that teachers should not lose sight of computational models when teaching CT. Computation has a plethora of uses, from self-driving cars to natural language processing, but the teaching about the principles of computational thinking should not get lost to the sea of usage models. CT is often seen as a bundle of programming tools (Tedre and Denning 2016, 120-129), which is not the whole picture. A narrow focus like this can quickly dampen students' motivation. Barriers mentioned by Tedre & Denning and Aho (Aho 2011; Tedre and Denning 2016, 120-129) are hard to study objectively via an interview and these are omitted from the study.

Institutions can encourage and enable the teaching of CT with resources, teacher education, competitions, and material. Even if teachers and institutions try to enable CT teaching, outdated or scarce resources can be barriers. (Buabeng-Andoh 2012) Even though CT teaching does not require computers, much of the free material is used with computers.

Categories may be overlapping and unambiguous. For example, lack of devices or lack of teacher education might be seen as an institutional problem instead of a personal or technological one.

2.3.2 Interventions to overcome the barriers of teaching CT

Interventions are ways to abolish or diminish the effect of the barriers. Interventions can be simple learning scenarios, changes in methods, a new pedagogical philosophy, institutional changes, or new ways of procuring equipment.

There are many "best practices" and a plethora of advice. Best practices are not necessarily easily executable or implementable in every school, institute, or country. (Hsu, Chang, and Hung 2018, 296-310) If there are personal, institutional, or technological barriers, then it is possible that the best practices cannot be implemented on their own. The change is slow, and institutions should encourage teachers to seek education and examples from other institutions. Guidelines help to understand what should be done, but they hardly ever give a simple pathway to follow. (Tedre and Denning 2016, 120-129)

(Hsu, Chang, and Hung 2018, 296-310) suggested five interventions for teaching CT effectively: educating faculty about CT, assessing students' learning performance, understanding students' learning status, designing CT training for different ages, and adopting the cross-domain teaching mode.

Faculty education is crucial. As Venkatesh (Venkatesh and Davis 2000, 186-204) described, teachers and faculty have to understand CT, its applications, possible implementations, and benefits for the students. If a teacher does not appreciate the skills and knowledge intermediated by CT, they will not teach it or give it the weight it deserves. Earle (Earle 2002, 5-13) found that change resistance can be eased with interventions and encouragement, such as teacher education, technical support, and time for planning. Teachers have to perceive technology as valuable and essential to give the needed emphasis to their students. According to (Buabeng-Andoh 2012), many teachers are hesitant to change the way they are teaching if they are told to or they have only read about. Teachers should observe and be part of a new type of lectures as part of their education to gain motivation and gust to do it themselves.

Teachers must have an unambiguous curriculum, and a path followed in all classes and grades to reasonably assess students' learning performance. Finnish organization, Innokas, created a clear pathway in poster form (figure 2) from the Finnish curriculum. (Ansolahti and Kukkonen 2013) The Finnish national curriculum itself is not clear or unambiguous. Innokas framework could be used when assessing learning performance in different grades.

Teachers have to be educated and motivated to understand student learning status. CT is not just a set of tools that have to be taught (Tedre and Denning 2016, 120-129), but a skill set that has to be trained on real-world problems. Teachers who have taken CT as a permanent part of their toolbox can understand and monitor their students' learning status. (Hsu, Chang, and Hung 2018, 296-310)

The last one of the interventions Hsu (Hsu, Chang, and Hung 2018, 296-310) mentioned is designing CT training for different ages and adopting the cross-domain teaching mode. According to Angeli & Giannakos (Angeli and Giannakos 2020, 106185) metaphors are a great way to transfer abstract ideas of programming to primary school students and should be emphasized in education. Angeli & Giannakos (Angeli and Giannakos 2020, 106185) also created a five-step cycle for advancing CT education (figure 3). The first step of the cycle is defining the key competencies in the CT. The next step is to mold competencies into metaphors to make abstract ideas easier to understand and create larger entities of information about abstract concepts. The third step is to try out and follow up on the effectiveness of pedagogies and technologies in developing CT competencies. The fourth step is to educate the teachers on intermediate CT and instruct them on integrating CT into their disciplines. The fifth step is to measure the accomplished CT competencies. This is a powerful perspective for teachers to evaluate their own material and examples.

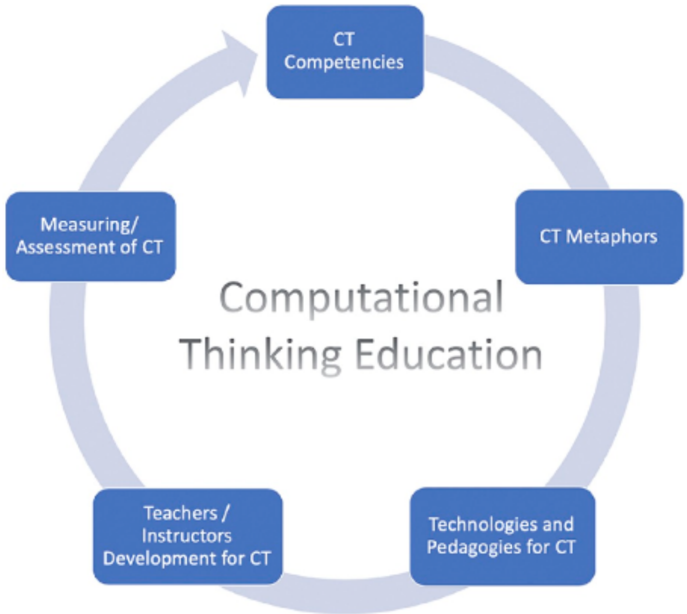

Figure 3. A five-step research plan for CT education (Angeli and Giannakos 2020, 106185)

3 Methodology

Based on the literature review (Okoli and Schabram 2010), an empirical study was conducted to understand the most common barriers to teaching computational thinking in Europe. A qualitative study (Miles, Huberman, and Saldana 2014) was chosen to identify possible new barriers not rising from the literature or curricula review.

The literature review was conducted via Google Scholar and search terms like "computational thinking teaching," "computational thinking barrier," and other related terms. The most recent articles were initially chosen and snowballed (Wohlin 2014, 1-10) to the older articles. Literature about the teaching of computational thinking is scarce, and the review process was not too labor-intensive. A barrier framework was constructed based on the literature review and is presented in chapter 2 (tables 1, 2, 3, 4). The interview questions were constructed with the aid of the framework. The framework was complemented with the results gained via the qualitative empirical study.

The study has to be considered qualitative even though it produces numerical data. Interviewee data is gathered as binary, and the severity of specific barriers is not taken into account. Only the frequencies of the barriers are considered.

For this study, a total of 41 teachers from four different countries were interviewed about teaching CT and other computer skills. The interview study (Kelley et al. 2003, 261-266) was a descriptive face-to-face survey with open questions. Participants were chosen through convenience sampling, targeting active CT, ICT and CS teachers. The questionnaire was more exhaustive (see appendix A), but this study is generated only focusing on questions 1, 2, and 9. Other parts of the questionnaire have been published in an article by Pawlowski (Pawlowski et al. 2020) and in later, still unpublished articles.

This study concentrates on the difficulties and barriers of teaching computer science and computational thinking basics to primary and middle school students. While the scope of this study is in grades 3-6, middle school, high school, and university teachers give valuable information about the skill set and skill level students have when they are entering middle school and higher levels. Results were tabulated and compared with different countries. All interviews were conducted, transcribed, coded, and analyzed by one researcher but validated by a working group of researchers to avoid subjective bias (Sarker and Sarker 2009, 440-461). Table 5 summarises the demographics of the interviewees.

3.1 Survey research

Surveys are used to gather information by asking for it from people affected by the phenomenon. Survey studies are divided into descriptive, analytical, and evaluation research. This study is descriptive research, as it concentrates on particular phenomena at a single point in time (Kelley et al. 2003, 261-266). The aim is to study the factors associated with computational thinking and gather opinions on experienced barriers and practices used to overcome experienced barriers.

3.2 Formulating the questionnaire

This study's interview questions were part of a more extensive international survey (Pawlowski et al. 2020) that was executed to get data on the current state of computational thinking education. The long-term goal of the project is to create material and study paths for teaching computational thinking.

Kelley (Kelley et al. 2003, 261-266) emphasizes that research questions must be clear and explicit when formulating the questionnaire and choosing interviewees.

> Research question 1: What are the current barriers to teaching computational thinking?
>
> Research question 2: How can these barriers be, or have been, overcome?

When the research questions are made clear enough, they can be asked and analyzed with as little interpretation or misunderstanding as possible. A decision was made to conduct the interviews as face-to-face interviews to allow as much elaboration as possible and make open-ended questions more feasible and the answers as unambiguous as possible. The questionnaire questions were discussed with the Computational thinking and acting (COTA) project team and refined.

Participants were chosen as a non-random convenience sampling, and the study was directed to active CT, ICT and CS teachers.

The questions related to this study were as follows:

1.Interviewee background data

- 1.1 Name
- 1.2 Role
- 1.3 Age
- 1.4 Level of education
- 1.5 Year of graduation
- 1.6 Teaching experience

2.School background data

- 2.1 Country, city:
- 2.2 Level:
- 2.3 Student age
- 2.4 School size

9. Barriers and Interventions

- 9.1 What are the main barriers to teaching ICT / computational thinking in your experience?
- 9.2 How would you overcome those?

The first two questions were needed to analyze the answers and categorize teachers respective to their country, their teaching level, and other personal factors. The last question is a direct question to study the research questions in the interviewees' schools, areas, and countries. Question 9.1 was also supplemented with an assisting question: Is there a lack of resources, lack of time, lack of support, no qualified teachers?

3.3 Data Collection

Participants were chosen from four countries taking part in the COTA project. Ten teachers were interviewed from each country (except 11 from Germany). Interviewees were chosen as a convenience sampling from teachers the researchers already knew were teaching CT or had been training teachers how to teach CT.

Country	**No of interviews**	**Levels of teaching***	**Age range**
Estonia	10	Primary level teacher (10), Secondary level teacher (7)	45-63
Finland	10	Primary level teacher (7), Secondary teacher level (2), Headmaster (2), University researcher (1)	30-46
Germany	11	Primary level teacher (7), Headmaster (2), University researcher (4)	30-50
Greece	10	Primary level teacher (7), Secondary teacher level (1), High school teacher (2), University teacher (2)	31-43

*Some teachers taught on various levels

Table 5. Summary of the interviews conducted

There are five potential limitations in interview survey studies, according to Bickman & Rog (Bickman and Rog 2008), and these were taken into account in the survey design. The first potential limitation is that interviewees decline the invitation to participate, and the willingness might bias the survey. The second limitation is that with group discussions, respondents interact and might lead to weaker generalizability of the results. Also, there might be a very dominant or opinionated member. Other members might be more hesitant to make their opinions heard. The third possible limitation is that the immediate nature of the interaction in the interview may lead the interviewer to think the findings in the interview are more significant than they would be. The fourth limitation is that the open-ended responses tend to make summarization and interpretation hard. The fifth limitation is that the interviewer might bias results by knowingly or unknowingly asking leading questions or providing inaudible cues about desirable answers. These limitations were taken into account in the design phase to minimize their effect.

Interviews were carried out in late 2019 and early 2020 as face-to-face interviews. Interviewees were asked to participate in the study, and interview time was agreed. Some interviews were executed via Zoom or Skype if a live interview was not possible. The COTA-team members carried out interviews in interviewee countries in their native language. Interviewers translated and transcribed interviews.

German interviews were carried out in groups, and the groups' answers were collated. Therefore there is no individual interview data on German interviewees. All other interviews were carried out and recorded individually to minimize biases and to record individual responses.

All interviewees were happy to participate, and none of the teachers denied when asked to participate.

3.4 Data analysis

As Kelley (Kelley et al. 2003, 261-266) stated, "The purpose of all analyses is to summarize data so that it is easily understood and provides the answers to our original questions."

Harding & Whitehead (Harding and Whitehead 2013, 141-160) have rigorous instructions for analyzing data in qualitative research and creating a descriptive exploratory study. The main goal is to gain new ideas and insight via inductive reasoning and iterative analysis of the interview material.

As this study focuses only on two questions of the interviews, the analysis is done manually without designated analysis software. Krueger (Krueger and Casey 2002) presents the old-fashioned way of a long table, scissors, tape, and color markers to find similarities and group them on large sheets of paper. The analysis was done similarly to Krueger and Harding & Whitehead (Harding and Whitehead 2013, 141-160; Krueger and Casey 2002), using Excel sheets. In Excel, every question was processed in a dedicated tab. The answer to each question was isolated from every interview and transcribed to one cell in Excel. After transcription, main points were collected from every answer to notes in the cell next to the answer. After every answer was processed, the answers were processed again to unify and standardize the answer notes. This iteration was done until answers were handled satisfactorily. As the notes were unified, the mentioned barriers were gathered to the following cells. The initial barrier categories found from the literature were used (in chapter 2.3.1), but new ones were found in the process, as some barriers did not fit into the ones found in background research. The barrier enumeration was also done iteratively to ensure uniform processing.

The total number of barrier types was counted, and the total number of each barrier type in each participating country. Barriers were categorized into three main categories, personal, institutional, and technological barriers. The number of barriers in each category was also enumerated according to participating countries.

Barriers were categorized as focused and unambiguous types as possible. Unambiguous categorizing is not always easy or even possible, which will be discussed in the Discussion chapter. Results are accompanied with comments from the interviewees to intermediate the thoughts and views of interviewees.

4 Results and findings

4.1 Interviewee data

Interviewees were all chosen from interviewers' networks and recommendations from network members. All interviewees work as teachers or principals or are teacher educators. The emphasis is on primary school teachers. Secondary school teachers have an excellent grasp of the student material they are receiving from different schools. High school and university teachers know what skills students have and what they should manage at that level.

As seen in Table 6, the majority of teachers are teachers or principals.

Role	Count
Teacher	30
Headmaster	5
Teacher Edu specialist	1
Uni lecturer	4
Educational technologist	1

Table 6. Roles of interviewees

The majority of the teachers are teaching in primary school (table 7)

Level	Count
Primary	**21**
Secondary	**4**
Both Primary & Secondary	**7**
University	**4**

Table 7. Interviewee teaching level

Table 8 has all the information of Estonian interviewees

Intervie-wee	Age	Teaching years	Role	Level	School size

EST1	63	39	Class teacher	K-12 age 8-12	93
EST2	49	24	Math teacher	Secondary school, age 7-15	93
EST3	45	23	Teacher	Secondary school, age 6-11	450
EST4	51	29	IT specialist, Computer Science and Robotics Teacher	Age 6-20	1000
EST5	62	23	Math and IT teacher	age 6-19	1100
EST6	59	37		age 7-19	950
EST7				7-16	161
EST8	59	22	Class Teacher	7-13	23
EST9	60	15	Class Teacher	7-16	530
EST10	53	32	Educational technologist	7-18	521

Table 8. Estonian interviewees

Table 9 has all the information of Finnish interviewees

Intervie-wee	**Age**	**Teaching years**	**Role**	**Level**	**School size**
FIN1	43	17	Teacher	Elementary Student age 7-12	235
FIN2	44	18	Principal	K-12 student age 7-12	300
FIN3	40		University Researcher	age 7-12	
FIN4	42	14	Finnish language teacher	age 13-16	400
FIN5	46	13	Math teacher	age 16-19	150
FIN6	30	4	Teacher	age 6-12	150

FIN7	42	16	Math teacher	16-19	330
FIN8	45	10	Teacher	age 6-10	170
FIN9	39	10	Teacher	age 6-12	250
FIN10	43	20	Principal	age 6-12	135

Table 9. Finnish interviewees

Table 10 has all the information of German interviewees.

Intervie-wee	Age	Teaching years	Role	Level	School size
GER1	50	25	Teacher/ Headmaster	Primary school, grade 1-4	240
GER2	30	3	Teacher	Primary school, grade 1-4	240
GER3	32	5	Teacher	Primary school, grade 1-4	240
GER4	30		Teacher	Primary school, grade 1-4	200
GER5	35		Teacher	Primary school, grade 1-4	200
GER6	40		Headmaster	Primary school, grade 1-4	200
GER7	50		Co-headmaster	Primary school, grade 1-4	200
GER8			Teacher education center		
GER9	40	12	Lecturer	University, age 18-28	
GER10	38	12	Lecturer	University, age 18-28	
GER11	46	12	Lecturer	University, age 18-28	

Table 10.German interviewees

Table 11 has all the information of Greek interviewees.

Interviewee	Age	Teaching years	Role	Level	School size
GRE1	36	9	ICT Teacher	Grades 1-4	2000
GRE2	34	10	ICT Teacher	Primary and high school	2000
GRE3	31	8	Class Teacher	Primary school	2000
GRE4	43	11	ICT Teacher	Primary school	2000
GRE5	28	5	ICT Teacher	Primary school	2000
GRE6	39	11	Class Teacher	Primary school	2000
GRE7	38	1	ICT Teacher	University teacher	8000
GRE8	35	13	Teacher (Economics, Computer science)	High school age 15-18	300
GRE9	36	6	ICT Teacher	University teacher	8000
GRE10	36	13	ICT Teacher	Primary and secondary school	300

Table 11.Greek interviewees

4.2 Summary of Barriers

Barriers were categorized into personal, institutional, and technological barriers described in table 1. Technological barriers were condensed to “Lack of resources” as the answers varied from lack of specific trademark devices to general “devices” or lack of access to the devices, and the comparability was poor. Barriers “Lack of time” and “No allocated subject” are different sides of the same coin. Lack of time could involve lack of personal time for teachers to educate themselves, lack of time to prepare material, and lack of time for teaching CT. Lack of time can also be seen as an institutional barrier, as there is no allocated subject to teach CT and therefore no allocated time or resources. The “allocated subject” was also presented as a solution for several barriers. In these cases, it was not noted as a barrier. The answers were interpreted individually into categories.

For example, a Finnish teacher answered the barrier question:

"There are devices for 1/5 of the students, which is enough for now. There is too little time in the curriculum. CT and ICT used to be taught in math class, but there is now less time for math in the current curriculum, but the material is still the same. CT is seen as extra material that will be taught if there is extra time."

The keywords were allocated to barriers divided into categories from these answers as presented in table 12.

Personal Barriers	Institutional Barriers	Technological Barriers
Change resistance	Lack of time	Lack of resources
Lack of teacher education	No allocated subject	
Teacher motivation	Lack of staff	
Motivation of students	Lack of material	
Heterogenous student skills	Group sizes	

Table 12. Categorization of found barriers

The categories were used when results were compared with specific countries. A breakdown of relative answers to different categories can be seen in Fig. 4.

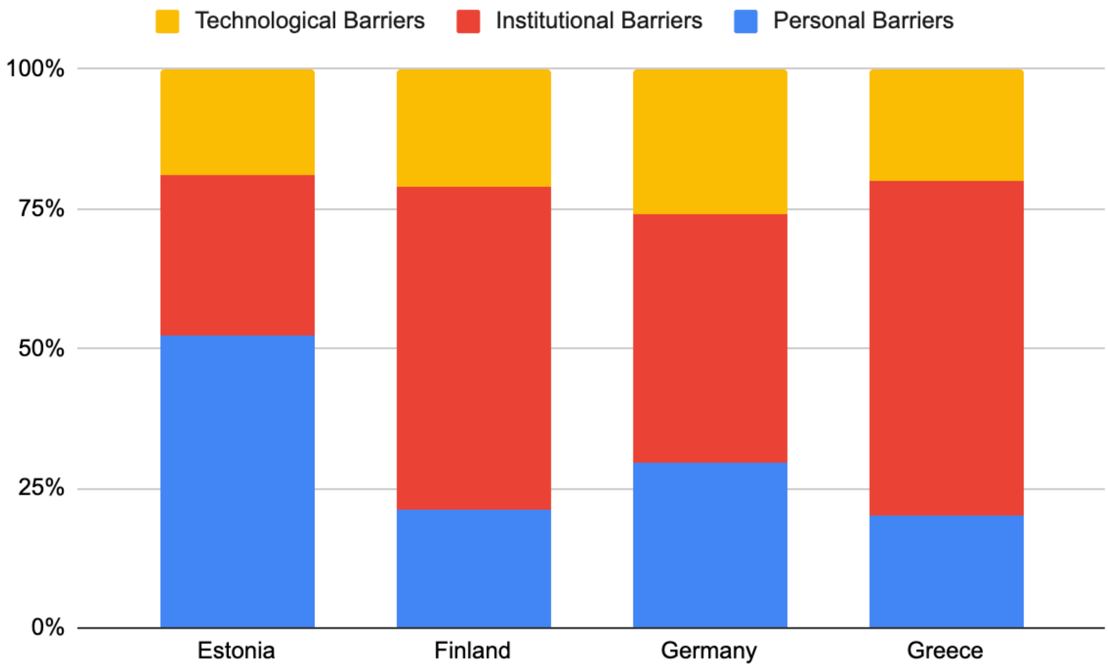

Figure 4. Relative distribution of the categorized barriers by country

All barrier types in each country and especially the differences between countries can be seen in figure 5.

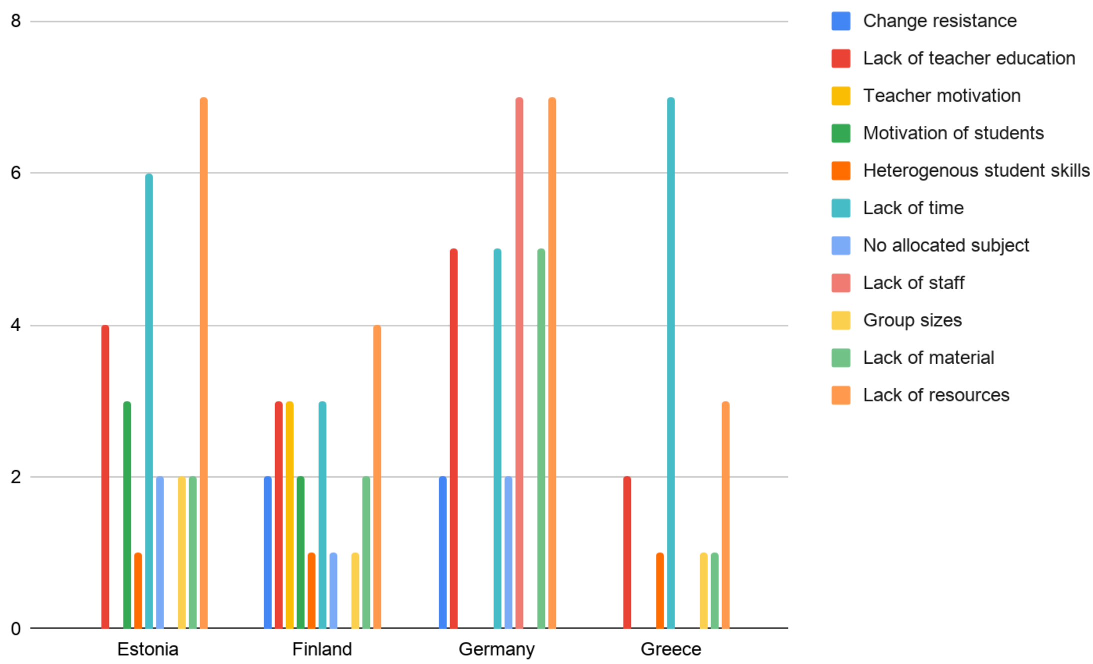

Figure 5. Frequency of barrier types in different countries

The distribution of the barriers with all the interviewees can be seen in Fig. 6. Certain barrier types stand out in the aggregated data and should be taken under closer examination in later research.

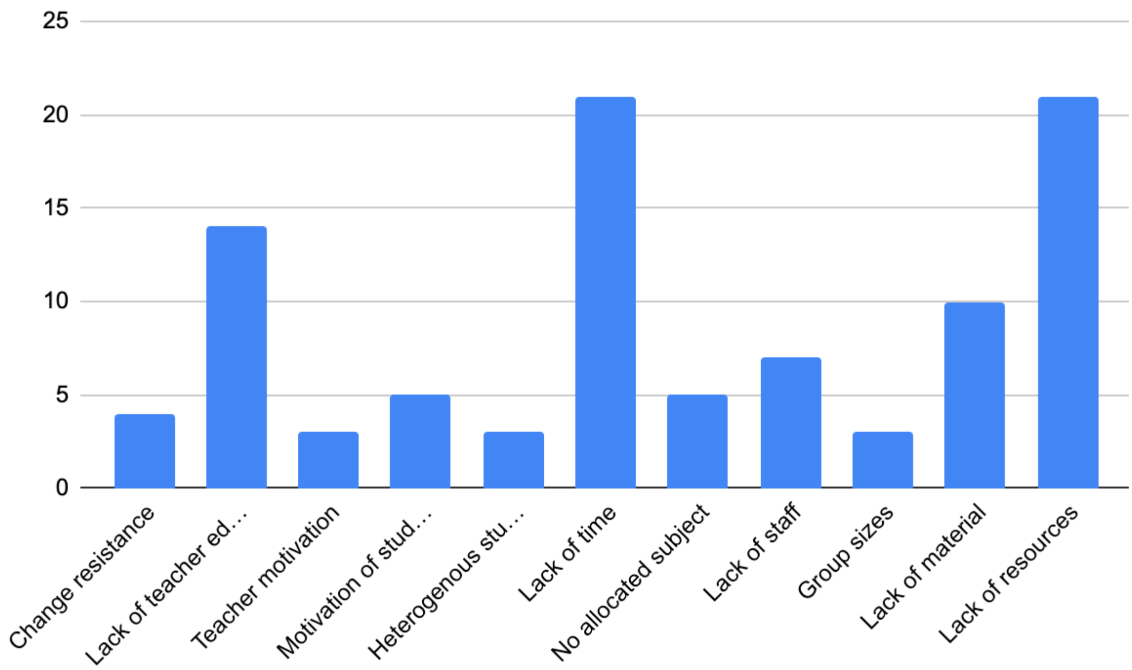

Figure 6. Frequency of barrier types over all interviewees

4.2.1 Estonian barriers

The most frequent barrier mentioned by Estonian teachers was the lack of resources (7/10). According to interviewed teachers, there is a lack of computers, space, and proper material for teaching CT and ICT. The barrier mentioned almost as often was "lack of time" (6/10), and 2/10 mentioned "No allocated subject." As discussed earlier, these are often different sides of the same problem.

Other frequently mentioned barriers were Lack of teacher education (4/10) and students' motivation (3/10). Group sizes (2/10), lack of material (2/10), and heterogeneity of student skills (1/10) were also mentioned.

4.2.2 Finnish barriers

Finnish barriers were different from all the others in a few ways. Finnish teachers named the lack of teacher motivation as one of the most significant barriers (3/10), while it got no mentions in other countries investigated. An almost similar barrier is change resistance, which was also mentioned (2/10). Lack of resources was the most common barrier (4/10), but almost all the other barriers were mentioned at least once. The only exception was the lack of staff, with 0/10 mentions.

4.2.3 German barriers

German teachers named Lack of staff and Lack of resources most often (7/11). Lack of teacher education, Lack of time, and Lack of material were frequently mentioned (5/11). German teachers were the only ones to mention lack of staff as a barrier. Other barriers mentioned were Change resistance and lack of allocated subject (2/11).

4.2.4 Greek barriers

Greek teachers named Lack of time as the most common barrier (7/10). Lack of resources was seen as a problem by 3/10 interviewees. Other barriers mentioned were Lack of teacher education (2/10) and Heteregenous student skills, Group sizes, and Lack of material with 1/10 mentions.

4.3 Interview results about the barriers

Interviewees were asked open-ended questions about the barriers they face when teaching CT. Below is a list of barriers with reasoning and argumentation from the interviewees. Focusing on one barrier at a time is not unambiguous as barriers often overlap and might have causal relationships.

4.3.1 Change resistance

Change resistance was mentioned as a barrier, especially for the older teachers (FIN5, FIN8, GER8, GER9), affecting how CT is taught and affected students' attitudes and attitudes towards CT. FIN2 said teachers are the most challenging group to teach something new to. Many teachers do not have the skills to teach CT, but they also experience that CT and ICT are comparable to magic and cannot be mastered. It is hard to motivate teachers to learn a new skill if they have had a 30-year professional career and want to do everything the way they have done before

4.3.2 Lack of teacher education

"Lack of teacher education" -barrier can be seen as a reason for or a result of change resistance. Many interviewees hoped for quality educational material for teachers and educational paths to gain self-esteem in a field that is experienced to be complicated by many (FIN3, FIN9, FIN10, GER8, GER9, EST1, EST2, GRE3). FIN3 said that many educational and professional development possibilities are available, but teachers do not attend them. Teachers that attend CT and ICT courses are the ones already savvy in CT and technology. The teachers that would benefit from the courses do not attend because they feel it is too difficult.

4.3.3 Teacher motivation

"Teacher motivation" -barrier was mentioned only by Finnish interviewees (FIN6, FIN8, FIN9). This barrier is closely related to change resistance and could be interpreted as the same barrier. FIN6 said that although CS is required in the Finnish curriculum, there are no clear guidelines or material to carry this out. Teachers are not "forced" to teach anything CT-related, as there is no measurement or public benchmark.

4.3.4 Student motivation

EST4 said that students do not recognize the importance of programming skills and the development of logical thinking. CS skills are experienced as "nerdy," and the application of basic CT is not clear (FIN8). FIN9 said that the few classes dedicated to CT and other CS skills are too few and too far apart to create understandable entities for students.

4.3.5 Heterogenous student skills

A few middle and high school teachers were involved in the study, and they experienced the heterogeneous skill levels of students as a significant barrier. The group sizes are often more prominent in higher levels, and individual instruction is more difficult in bigger groups. FIN7 compared this to if some primary schools allowed illiterate students to proceed to middle school. That situation would overwhelm teachers, but that is now the case in CS skills. There are national and regional CS guidelines, but they are not followed in every school. If the path is broken at one point, it will be broken up till high school.

4.3.6 Lack of time

“Lack of time”-barrier was mentioned most often. Interviewees felt that the curriculum is too tight to experiment with new topics.

“There is too little time in the curriculum. ICT used to be taught in math class, but there is now less time for math in the current curriculum, but the material is still the same." (FIN1)

GRE6 and EST6 said that the CT activities are based on an optional level, not allocated time. If CT is taught more, other subjects have to be rushed forward.

German interviewees (GER1, GER2, GER3, GER10, GER11) said they do not have time to instruct students in ICT classes. A helpful hint in math class might take 10 seconds, but ICT problems take a lot more time to solve. Lack of time was also given as a reason for not attending courses or other training.

Lack of time also means that teachers do not have time to develop new exercises or activities. Many teachers are overworked and do not have time to enhance their professional skills (EST3).

One class is only 45 minutes long. Getting the class started, bringing laptops from storage, booting them, waiting for possible installations, and solving wifi- and login problems easily takes 1/3 of the whole class. There has to be time for saving the activities and returning the computers to the storage. In the worst case, there are only 20 minutes of effective time for activities. (GRE2)

4.3.7 No allocated subject

"No allocated subject" -barrier is similar to lack of time and lack of material. It was also suggested as a solution for many other barriers. If CS had a designated subject with its allocated time and grading, most of the barriers would be solved at least partly. (EST6, EST9, FIN1, GER8, GER9) As long as it is not an individual subject but is supposed to be integrated into other subjects, the quality depends on the teachers' activity and the support from the government, region, school, and other teachers. If CS had a designated subject, publishers would rush to provide material for teachers. Now the lack of curricular integrity makes creating material difficult.

4.3.8 Lack of staff

German teachers mentioned the lack of staff and made teaching new material more difficult (GER10 and GER11). Lack of teachers and assistants makes group sizes larger, which results in more restless groups, making individual instruction very difficult. Individual guidance is crucial in the early stages of learning new skills. CT and ICT often require several minutes of attention for every student, and giving enough attention is a struggle with large groups.

4.3.9 Group sizes

Group sizes were mentioned several times (EST3, EST5, FIN7, GRE5). FIN7 said, "Students cannot be individually educated if there are 30 students and one teacher." Classes are often divided into craft subjects like music and art classes. CS should be seen as a similar subject, where a teacher has to attend to one student for some time.

4.3.10 Lack of material

Many interviewees mentioned the lack of quality material, study path, and continuum of skill development in later grades. “CS is required in the curriculum, but no clear guidelines or material is given,” FIN6 explains. GER10 and GER11 say they do not have designated books, apps, or other material. Teachers use what they have found or created themselves. Many teachers feel they have been left alone in this matter. EST6 said, “We need workbooks and a manual for the teacher to study computer science. Teachers need to develop their algorithmic thinking skills: understanding what an algorithm is, the main types of algorithms, cycles, and graphs. We would need material in a game form for elementary grades - preparation for studying the basics of programming in a primary school”.

4.3.11 Lack of resources

Some interviewees said they lack the devices altogether, others complained about outdated machines or the variety of devices (EST1, EST2, EST5, EST6, FIN1, FIN2, FIN3, GRE6, GER9, GER10, GRE8, GRE9). A common complaint was also that there are no devices in classrooms and they have to be fetched at the beginning of the class. Picking up computers consumes the limited time reserved for the class. Outdated equipment requires more time for every task and should be maintained, but there is not always anybody to take care of that. The procurement process is not involving teachers enough. Optimal devices and software are not always bought and cannot be replaced after procurement.

4.4 Suggested interventions and solutions

Questions about possible solutions and interventions were asked among the questions about the barriers. If there were easy answers, the barriers would be problems of the past. The suggested interventions divided into their respective categories are listed below.

4.4.1 How to ease change resistance

Change resistance was mentioned as a barrier for the older teachers (FIN5, FIN8, GER8, GER9). This problem could be dealt with by letting time pass and waiting for the generational drift as the older teachers retire. FIN2 suggested that CT education should be started with teachers that are eager to do it. As rough edges have been smoothed, learning from other teachers would be easier for the more resistant teachers. Interviewees said peer pressure would apply only after most teachers are willing and able to teach CT. FIN10 thought that teachers want to master a subject before teaching it and said teachers should be encouraged to tinker and try using CT tools themselves during their free time. GER8 and GER9 wished parents were involved and engaged to enable a more familiar and systematic education at home and school.

4.4.2 Enhance teacher education

Most interviewees hoped for systematic education for teaching CT and ICT skills (FIN3, FIN9, FIN10, GER8, GER9, EST1, EST2, GRE3). As GER8 and GER9 argued, if education is arranged only for those studying to be future teachers, the change will be too slow. One interviewee hoped that universities would create courses and materials for teachers. That would ease teachers' education while working (FIN3).

4.4.3 Enhance teacher motivation

There are benchmarks for reading, writing, and mathematics. Maybe similar tests might motivate teachers to try harder to grasp how they could effectively teach CT (FIN6). Tests would also create a level everyone has to pass, and teachers could create a path to follow. FIN8 commented, "Teachers should be educated in small steps, so they could not resist it, as it is just a small task."

4.4.4 Enhance motivation of students

The importance of CS skills should be advocated publicly and via material teachers can use in the classes (EST4). FIN8 suggested that students should be involved in the planning of courses and content. EST9 argued that increasing the number of hours and reorganizing CT and ICT curriculum could help.

4.4.5 Equal student skills

Interviewees said that securing a specific skill set and level for each student would make education a lot easier for students and teachers at higher levels. FIN7 suggested that students need an ICT path that must be followed at every level and tested at least once a year. EST3 mentioned that students are happy to help each other out if given a chance.

4.4.6 More time for CT

Lack of time was mentioned most often, and interviewees suggested a variety of solutions. Several interviewees suggested giving more time to the curriculum (FIN1, EST4, EST6, GRE6, GRE8). Several German interviewees suggested hiring additional staff to ease the burden from teachers teaching CT and ICT (GER1, GER2, GER3, GER10, GER11). EST2 suggested that after-school clubs give additional education if the curriculum is not flexible enough.

4.4.7 Create an allocated subject for CT

No allocated subject -barrier was suggested as a barrier, and adding CT as a subject to the curriculum is an obvious solution. Rationalization and reasoning are essential here. If there is no allocated subject, teachers allocate time themselves and not necessarily in the same way. There is no mapping of CT to traditional subjects. CT and ICT should be compulsory and given a certain number of hours every week, required by the state educational program. (EST6, EST9, FIN1, GER8, GER9)

4.4.8 Hire more teachers and staff

German teachers complained about the lack of staff and how that makes teaching new material more difficult. GER10 and GER11 suggested a political solution to raise teacher salaries and increase the universities' production of new teachers.

4.4.9 Decrease group sizes

Group sizes were mentioned several times. According to EST3, a group size of 12 would be ideal for teaching CT and ICT. EST5 suggested a second teacher in CT classes.

4.4.10 Create material for teaching CT

EST6, FIN6, and FIN7 suggested that the government or publishers created material independent of devices, operating systems, and software. The material should include games, plays, videos, exercises, and some hard copy books. GER1, GER2, and GER3 hoped for cross-subject CT and ICT-material that could be used in class. GER10 and GER11 suggested tailor-made apps for teaching CT. FIN3 hoped for a platform for active CT and ICT -teachers to share their experiences and the material they have created.

4.4.11 Allocation resources

The most commonly suggested solution for lack of resources was more generous funding (FIN2, GER9, GER10, GRE6, GRE8, GRE9). EST 5 said a separate specialist is needed at the school. The specialist would be engaged purely in preparing the equipment for the lessons, charging and cleaning devices, installing the necessary programs, and delivering them to the teacher before the class. FIN3 hoped that schools could buy kits similar to physics or chemistry classes, where there would be enough material and devices for specific exercises and projects. EST1 and EST2 suggested that schools find sponsors and investors to obtain more devices. EST3 even suggested hiring a person to write projects and reports to get grants. EST6 said Estonian Information Technology Foundation for Education (HITSA) had solved resource problems by granting funding for schools to buy devices and software licenses.

5 Discussion

The empirical study confirmed most of the previous findings rising from the literature (table 1). In addition to the previous literature, lack of student motivation was also seen as a barrier to teaching CT. Lack of student motivation might be due to the obscure study path, and as Tissenbaum (Tissenbaum, Sheldon, and Abelson 2019, 34-36) said, “[...] initial focus on the concepts and processes of computing, leaving real-world applications for "later" runs the risk of making learners feel that computing is not important for them.” Motivating students is one part of educators’ work, and it would be made easier with a clear study path and real-world applications.

The interview data shows that there are barriers everywhere, and certain barriers are viewed as more severe than others. This study is qualitative and was not trying to quantify the severeness of barriers, but there is a need for such study. Specific barriers were emphasized in some interviews, even though they did not get many mentions overall.

The interviewees stated that they did not have enough time to teach computational thinking, as the time would be taken from other subjects. The time to familiarize and prepare the CT material would need commitment from teachers, as Vannatta & Nancy (Vannatta and Nancy 2004, 253-271) showed. The curricula are built quite tight and are often implemented strictly via books. If the books do not discuss CT, the teachers rarely bring it up, which is seen as an extracurricular activity. Additionally, according to interviewees, there is no ready-made material or material for study paths that the teachers could follow. Material is made and shared by teachers, but consistency and quality are often in question. In terms of curricula, computational thinking does exist with topics and goals, but the implementation of teaching itself is left to the teachers. Well thought and well-made material would encourage the teachers to try out different approaches and would probably diminish change resistance. The interviewees, who were active ICT and CT teachers, said they would need more training and institutional support to learn how to teach CT better and more effectively.

Lack of resources was a frequent barrier, according to the interviews. Computers, Beebots, Lego Mindstorms, and other devices were often outdated and scarce. Many schools had shared-use computers that had to be reserved for use and could not be trusted to have energy in the batteries or work without problems or need for updates. A Finnish teacher said bringing the computers to the class was “Always a hassle. There are always a few students who have problems with their computers, which consumes time from studying. Fifteen minutes of hassle means 1/3 of the whole class.” Finnish teachers also brought up having ready-made kits for specific exercises that could be bought to the school. Buying ready-made kits is a regular practice in physics and chemistry. Teachers are getting paid extra to keep the kits up to date and in working condition, at least in Finland.

Student skill heterogeneity was seen as a problem, especially by the middle school teachers. New students come from several primary schools, but middle school teachers cannot assume they have any skills to build on. Students of different primary school teachers had very different sets of essential skills and knowledge, which will be problematic once the students advance to the next level. A Finnish teacher commented, “Some are fluent with email, office programs, some basic programming, and basic algorithms; others have not even sent an email. Heterogeneity of skills consumes the time resources and makes it impossible to teach anything that every student would see as novel, interesting and meaningful. Imagine if we got some students that do not know how to read or do basic math, it would be an outrage!” Without unambiguous definitions and guidelines, implementation varies a lot between schools and even between teachers. For example, in the Estonian curriculum, digital competence is one of the mandatory general competencies required to develop (Lauringson and Rillo 2015). However, most interviewed Estonian teachers state that they would need more time, resources, or teacher education to carry this out.

Frequently suggested solutions to break the barriers were well-written materials with a clear study path from a publisher. A publisher's involvement would guarantee the quality and consistency of the material. Individual subjects for ICT and CT were also mentioned frequently. Isolating ICT and CT as a subject would mean reworking the curricula, but it was seen as a powerful solution to solve teacher motivation, teacher education, heterogenous student skills, and the material barrier. Teacher training should be advanced, even though most interviewees said they had training when requested.

Resource barriers are seen to be solved only by money, well-made and well-thought procurements, and continuous upkeep. Procurements were said to be concentrating on the monetary value instead of the pedagogical or teacher time consumption perspective. Interviewees said that teachers are the professionals using the tools and should be involved in procurement.

Barrier	Example	References	Contribution of this study
Change resistance	Teachers do not want to change the way they are teaching	(Balanskat 2006; Bingimlas 2009, 235-245; Cox, Cox, and Preston 2000; Denning 2017, 33-39; Schoepp 2005)	Change resistance was reported by four interviewees and was said to be the problem of older teachers. This seems to validate the findings in the literature.
Lack of teacher education	Teachers do not know how to teach CT effectively	(Balanskat and Engelhardt 2014; Balanskat 2006; Buabeng-Andoh 2012; Ghavifekr et al. 2016, 38-57; Hus 2011, 3855-3860; Keong, Horani, and Daniel 2005, 43-51; Kind 2009, 1529-1562; Shulman 1986; Stokke 2019)	Lack of teacher education was the most reported barrier in the Personal category. According to the literature, teacher education is also the most likely intervention for other barriers in the personal category.
Teacher motivation	Teachers know how they could teach CT but do not see why they should do it	(Beggs 2000; Balanskat 2006; Bingimlas 2009, 235-245; Cox, Cox, and Preston 2000)	Lack of teacher motivation was described to be a problem if teachers could not see the benefits of teaching CT, even if they knew how to teach it.
Motivation of students	Students are not willing to study CT		Lack of student motivation was described to be a problem only by Finnish teachers. Students did not know where they could use their CT skills and were hard to motivate. This barrier was not described in the literature review.

Hetero-genous student skills	Teachers have a hard time arranging the classes when skill sets vary from one student to another.		Middle and high school teachers reported heterogeneous CT and ICT skills as a barrier. Students arriving from different schools had unequal training in primary school and could not be taught together easily.

Table 13. Personal barriers in literature review and this study

Barrier	**Example**	**References**	**Contribution of this study**
Lack of time	Teachers do not have time to teach CT among other material or do not have time to prepare the classes.	(Balanskat 2006; Bingimlas 2009, 235-245; Ghavifekr et al. 2016, 38-57; Hus 2011, 3855-3860; Keong, Horani, and Daniel 2005, 43-51)	Lack of time was the most mentioned barrier in the institutional category. This barrier was also emphasized in the literature.
No allocated subject	There is no allocated time, framework, pathway, or standardized tests for CT.		Lack of allocated subject was not found in the literature as a barrier. A designated subject was also suggested as an intervention for many of the barriers.
Lack of staff	CT problems need longer attention from teacher per student than "traditional subjects," and there is not enough time to attend to every student.		Lack of staff was reported only by German teachers. This was not found in the literature, but this is similar to the group size barrier. More teachers per student are allocated if there is more staff or if group sizes are reduced
Group sizes	CT problems need longer attention from teacher per student than "traditional subjects," and there is not enough time to attend to every student.	(Balanskat 2006; Bingimlas 2009, 235-245)	Large group sizes and the attention needed from teachers were mentioned in the literature and the interviews.

Lack of material	There is no ready material the teachers could use in class.	(Keong, Horani, and Daniel 2005, 43-51)	There is a need for quality material that would advance logically and would contain extra exercises to individualize and differentiate teaching for students with different skills. This was mentioned only by one article reviewed but by ten interviewees.

Table 14. Institutional barriers in literature review and this study

Barrier	Example	References	Contribution of this study
Lack of resources	There are often problems with shared computers. Such problems include computers are out of battery, need an update, or will not find WiFi.	(Ayllón et al. 2020; Balanskat 2006; Bingimlas 2009, 235-245; Fraillon and others 2020; Ghavifekr et al. 2016, 38-57; Keong, Horani, and Daniel 2005, 43-51; Nikolopoulou and Gialamas 2016, 59-75; Vannatta and Nancy 2004, 253-271)	Half of the teachers interviewed mentioned outdated or cumbersome computers or software. Also, a lack of robots and other resources was mentioned. This was also mentioned in many studies reviewed.

Table 15. Technological barriers in literature review and this study

Literature about the barriers is still scarce. In a thesis, Tom Stokke (Stokke 2019) mapped the understanding and knowledge of teachers about CT in the US. The study found that most of the participants did not have a working understanding of CT. The main barrier, according to that study, is that the teachers do not understand it. A different perspective was taken in this study as only active ICT, and CT teachers were interviewed, but the same barrier rose from this study.

Many barriers have causal relationships between them, and they can be removed only by an iterative process. For example, the teachers have to know what CT is to understand the benefits. As Tedre & Denning (Tedre and Denning 2016, 120-129) wrote, CT is a thinking tool, and teachers do not necessarily need devices or physical resources to get started.

Lack of material is a barrier that might be a cause for lack of student and teacher motivation. With well-made material used in all schools would also reduce the heterogeneity of students.

Imagine how varied middle school math classes would be if every primary school teacher had made their own material and used whatever they found on the internet. Publisher quality books would set a standard for the teachers for their knowledge and students' education.

5.1 Recommendations and good practices

Some recommendations and good practices arose from the review of the literature and the interviews carried out.

Teachers need to be educated about CT and the benefits of it. When teachers know what the CT in the curriculum means, they can start teaching it. One year after the interviews were carried out, one Finnish interviewee contacted the author and told their city provides new micro-courses about CT and ICT. When completing a micro-course, teachers earn badges to show their knowledge. One micro-course takes only 5-10 minutes to complete. Teachers get a badge from each micro-course, and certain combinations of badges aggregate to bigger badges. There is a gamification perspective in this system, as teachers want to have all the possible badges they can to get the bigger badges. Principals can follow how their teachers are advancing and can contact teachers who are not doing the courses.

Institutes can allocate some working hours for professional development. In Finland, there are so-called "VESO-education days," a clause in the contract of employment that requires teachers to educate themselves a certain amount of days during a school year. Teachers will also need time to prepare the classes and the material for them.

Student motivation can be improved with examples of how and where the CT skills can be used and their benefits.

Schools and institutes should give teachers regular opportunities for educating themselves via collaboration and reflection with colleagues. It is vital to discuss pedagogy, instructional practices, and research-based practices as most of the teachers have not studied CT during their own education. Procurers of resources should be involved in these discussions to make sure teachers get the resources they need.

Teachers need teaching material, and this should be considered nationally or even internationally. Quality books and websites with a logical path to advance would help teachers know what their students should be learning. It would force teachers resisting change to change their attitude instead. It would also motivate teachers as it would quickly show if students were lacking their education demanded and promised in the curriculum.

While there is not publisher-made material, the material is created voluntarily. By sharing created material and practices, teachers can create an environment for better CT education. Schools and cities could facilitate this knowledge sharing in their areas.

If students had their personal computers, they would always be up to date, charged (or the lack of charge would be known), any faults would be taken care of, and students might be more interested in the computers. It would mean a significant investment from the schools and might be unobtainable by many cities. Up-to-date computers are a budget issue and might need a multipronged solution. Possible solutions include leasing the computers or buying them as a service, making the budget easier to estimate and distribute the expenses evenly on school years.

Teachers should be involved in software and hardware procurement. Teachers are the ones that know what programs and attributes are needed and have to use the resources daily. The cheapest option might be useless and, therefore, a waste of money.

The summative evaluation of ICT and CT skills should be brought to discussion. There is a gap between evaluating CS skills and the needs later in the students' lives. Evaluation should move towards showing skill rather than simple recall of concepts.

Teachers should be allowed and encouraged to tinker and try out new technologies and pedagogical games and appliances. It can be encouraged by letting teachers buy pedagogical toys and tools with a budget of their own.

6 Conclusion

This study aimed to identify the most common barriers to teaching computational thinking in primary schools. The findings of this study support previous findings in published research on the topic. The most common barriers found in all countries were lack of time, lack of teacher education, lack of material, and lack of resources. However, the results vary between countries. Interview data show that German and Estonian teachers find the lack of resources as the most common barrier, while Greek teachers find lack of time as the most common barrier. Finnish teachers were the only ones finding teacher motivation as a barrier. In addition, another barrier identified was the gap between the summative evaluation methods of CT and the actual skills needed later in professional life. One significant barrier not found in the literature review, but encountered in interviews, was student skill heterogeneity. This barrier should be brought to national discussion to find ways to overcome the barrier. Certain barrier types stand out in the aggregated data and should be taken under closer examination in later research (figure 6). These are lack of teacher education, lack of time, and lack of resources.

The new barriers found in this study are also worth a closer look. Student skill heterogeneity and student motivation were identified as barriers, and the few suggested interventions could be tried out in a future study. Heterogenous student skills were a barrier, and in a future study, it would be interesting to determine how much skills differ in an age group starting in middle school at a specific year. Creating exciting and coherent material could be a solution for most personal barriers and should be studied more closely. The findings of this study are benefitting teachers and school board members, and also publishers of textbooks. The found interventions should be taken into the discussion when national and local curricula are planned.

The data and results about the barriers have been published in INTED2021 Proceedings. (Muilu, Mehtälä et al. 2021). Another article is written about the data and results of interventions.

6.1 Critique to the study

The sample for this study might not be objective enough to be generalized to all teachers. The interviewees are active teachers, but all of them teach ICT, CT, or integrate them into education, introducing a bias towards specific barriers. They were answering for themselves but also reflected the perceived attitude and encountered barriers of other teachers. In any case, this is a good starting point for studies to come, where more generalizable guidelines could be drawn.

Interviewed Greek teachers were teaching in a well-funded private school and are likely to have more minor problems with resources than an average Greek school teacher.

German interviews were pooled into groups of 2-4 which raised the barrier counts quite quickly. In some German interviews, the school principal was present, which might dampen criticism towards the institution.

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Appendices

A Interview form

1. Interviewee background data

    1.1 Name

    1.2 Role

    1.3 Age

    1.4 Level of education

    1.5 Year of graduation

    1.6 Years of teaching

2. School background data

    2.1 Country, city:

    2.2 Level:

    2.3 Student age

    2.4 School size

3. ICT in curriculum

Is there a school, regional, or national-level curriculum for ICT education? How is it implemented? Is it compulsory? In which topics of the curriculum could you see computational thinking skills to fit/to be learned?

4. Teaching ICT

How are the digital skills taught and learned? Games, playing, lectures, challenges?

5. Support for the teachers

How are teachers been supported? Are there education, monetary support, or support groups? Is the education ongoing?

6. Collaboration

Is there any collaboration with private companies, universities, or ministries?

7. Digital skills

What are the main goals of the ICT curriculum? Here is a short list of different goals as support for the discussion:

Students

- Can use programs (not writing them) to solve problems
- Can use ICT as a tool for learning
- Have digital competence, including media literacy
- Understand computational (algorithmic) thinking
- Can think logically and understand the principles of it
- Are better in problem-solving
- Can write and debug computer programs
- Have a grasp of one or more programming languages (Java, Python, C++, or similar languages)

8. Overall question:

Describe your experience teaching computational thinking by physical computing activities in your classroom? Explain what did you learn, what kind of difficulties did you face? What kind of benefits would you describe for these methods. What was the students' response/motivation/engagement like?

9. Barriers and Interventions

What are the main barriers to teaching ICT / computational thinking (e.g., lack of resources, lack of time, lack of support, no qualification)? Do you have ideas on how to overcome those?

Barrier	Intervention

10. Needs

Do you think that Computational Thinking should be taught between grades 3 and 6?

Do you think the approach of physical computing is feasible and helpful?

What do the schools and educators need?

What would the students need?