A Review of Models for Introducing Computational Thinking, Computer Science and Computing in K–12 Education

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***Abstract*—Computer science is becoming ever increasingly important to our society. Computer science content has, however, not traditionally been considered a natural part of curricula for primary and secondary education. Computer science has traditionally been primarily a university level discipline and there are no widely accepted general standards for what computer science at K–12 level entails. Also, as the interest in this area is rather new, the amount of research conducted in the field is still limited. In this paper we review how 10 different countries have approached introducing computer science into their K–12 education. The countries are Australia, England, Estonia, Finland, New Zealand, Norway, Sweden, South Korea, Poland and USA.**

The studied countries either emphasize digital competencies together with programming or the broader subject of computer science or computing. Computational thinking is rarely mentioned explicitly, but the ideas are often included in some form. The most common model is to make computer science content compulsory in primary school and elective in secondary school. A few countries have made it compulsory in both, while some countries have only introduced it in secondary school.

I. Introduction

In recent years, we have witnessed an active discussion surrounding the role of programming and computing for everyone (see e.g., [1], [2]. As a result, an increasing number of countries have introduced or are in the process of introducing computing in their school curriculum. For instance in Europe, the majority of countries (17 out of 21) taking part in a survey conducted by the European Schoolnet reported doing so [3]. The way in which this is accomplished varies. Some countries focus on K–12 as a whole, whereas others primarily address either K–9 or grades 10–12. Some countries have introduced computing as a subject of its own (e.g. England [4]) while others have decided to integrate it with other subjects, by for instance making programming an interdisciplinary element to appear throughout the curriculum.

While the former approach seems like the most straightforward alternative, there are different reasons for why some countries are opting for the latter alternative: 1) lack of space for introducing a new subject in the curriculum, 2) letting students see and experience the use of programming in different subjects is seen as a way of raising interest among previously underrepresented groups, and 3) computational thinking is considered more and more important in all areas of society, and provides us with a framework for how we can work together with the computer to solve increasingly complex problems. As computing has traditionally been primarily a university level discipline, there are no widely accepted general standards for what computing at K–12 level entails. Also, as the interest in this area is rather new, the amount of research conducted in the field is still limited.

Some overviews of K–12 computer science education exist. Grover and Pea reviews research on computational thinking in K–12 [5]. Mannila et. al. gives an overview of activities in K–9 [6]. Baarendsen et. al. gives an overview of concepts used in K–9 education [7]. Hubwieser et. al. [8], [9] gives a bird's eye view of K–12 computer science education.

For this article we have conducted a review of different models for introducing computing (programming, computational thinking) in K–12 education. The aim is to synthesize current practice and thereby contribute to the general understanding for different approaches to introducing computing at school. We have focused on curricula or plans in the following countries: Australia, England, Estonia, Finland, New Zealand, Norway, Sweden, South Korea, Poland and USA.

For each country, we briefly describe the local educational system, the current status of computing in the curriculum and the current status of teacher training. We are interested in understanding different models for introducing computing or some aspect of computing in K–12 education. Important questions are: What is being introduced? In what subjects? What does the progression look like throughout the education system? What are the desired effects of the changes? Which teachers are responsible for the new content? What type of professional development is provided to the teachers? Are teacher education programmes affected by the changes? How are the efforts expected to be evaluated? How is teaching material being developed?

II. Terminology

Whereas Computer Science is the established academic term for the scientific discipline underlying the current digitalization and information technology, there is no clear agreement on what term to use at lower levels of education.

Computer science, computing and informatics refer to more or less the same thing, that is, the entire discipline. *Programming and coding* are commonly used as synonyms. The European Schoolnet report "Computing our future" [3], showed that most European countries use programming or coding in their curriculum.

Furthermore, *computational thinking*, a term coined by Papert in 1996 [81], and gaining traction in 2006 through a seminal article by Wing [82], has seen a large increase in popularity during recent years. There is no agreed upon definition of computational thinking, but it builds on "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be carried out by an information-processing agent" [83].

All of the terms mentioned above differ greatly from *information (and communication) technology (IT, ICT)*, which mostly focus on computer literacy, that is, knowing how to use computers and their applications as tools.

In the following, we will use *computer science* as the umbrella term when discussing the situation in general. When referring to specific countries, we will use the term used in their documents.

III. Methodology

We decided to include ten countries in our study, covering Europe, USA, Asia and Australasia: Australia, England, Estonia, Finland, New Zealand, Norway, Sweden, South Korea, Poland and the USA. Some of these have introduced computer science in the official curriculum, whereas others are in the process of doing so.

The study was done by reviewing relevant documents for each country. Each author reviewed 3–4 countries. In situations where somebody was indecisive about how to report on a given matter, all authors jointly discussed the topic at hand. For countries, where computer science has already been introduced, we focused on the corresponding official documents. For those, where no official guidelines are available, we used other documents in the form of, for instance, articles and white papers.

In order to give an overview of ways and models for how computer science can be introduced, we selected the following criteria of interest (where applicable) when reviewing the documents:

- Term used (cf. the discussion in Section II above)
- Role in primary level curriculum (compulsory/elective/other)
- Role in secondary level curriculum (compulsory/elective/other)
- Integrated or a subject of its own
- Suggested progression
- Teachers responsible for covering the material
- Teacher training (in-service and pre-service)
- Teaching material

In addition to comparing the situation in a selection of countries, we also wanted to review to what extent the academic community studies the introduction of computer science in local curricula. To shed some light on this aspect, we looked at the proceedings of a few selected conferences:

- Australasian Computing Education Conference (ACE), 2005–2016
- International Workshop on Computing Education Research (ICER), 2005–2015
- International Conference on Informatics in Schools: Situation, Evolution and Perspectives (ISSEP), 2005, 2006, 2008, 2010, 2011, 2013–2015
- Integrating Technology into Computer Science Education (ITiCSE), 2005–2015
- Workshop in Primary and Secondary Computing Education (WiPSCE), 2012–2015

For each conference we marked all publications concerning the design of K-12 computer science and related teacher training. For each such publication we also took note of which country/countries it discussed.

IV. Review of models

A. Australia

The Australian primary and secondary school system has undergone a period of change, with the introduction of a National Curriculum [11]. In 2015, Australia [86] endorsed the Australian Curriculum: Technologies [87] that incorporates both Digital Technologies and Design and Technology. Within Digital Technologies (DT), children are to develop computational thinking skills and learn about data, digital systems and how to implement solutions with programming. DT in the Australian curriculum is a "learning area" in its own right, on par with English, Mathematics, Science, Humanities and Social Sciences, The Arts, Health and Physical Education, and Languages. ICT capabilities, as a whole, correspond to learning objectives in the DT learning area as well as objectives spread out over all other learning areas.

In Australia, primary school includes the first year of school, called Foundation (F) followed by year 1, and so on, until year 6 or 7 (depending on the state). Secondary school (also known as high school) includes years 7 or 8 to year 12. The curriculum learning objectives are organised around a series of Year level "bands", from F to Year 10, with senior year levels awaiting final development. While junior year objectives are mandatory, senior year students may select specialized strands in the DT learning area.

The DT curriculum has a strong focus on computational thinking skills and the development of both digital literacy and computational thinking commences in the F–2 band. Learning is based around directed play, facilitating students in developing an understanding of the relationship between real and virtual worlds, the use and purpose of technology in communication and the importance of precise instructions and simple problem-solving in the digital world. In years 3–6, students are guided to develop a wider understanding of the impact of technology, including family and community considerations, and are able to work on, and communicate about, more complex and elaborate problems. In this year level, students begin to develop algorithms with visual programming software. Across years 7–10, students move beyond their initial community and are required to consider broader ethical and societal considerations. Students solve more sophisticated problems using technology, and develop an understanding of complex and abstract processes. Students use programming languages to solve problems and create digital solutions.

Australian primary school teachers are typically generalist teachers, trained to teach across the various learning areas prescribed by their state or territory, with only 6% (n=7,500) currently teaching computer science [88]. To provide teachers with appropriate support, initiatives such as a professional development MOOC [88] and a systematic review of CS resources fit for the DT curricula [89] have been instigated.

B. England

In England, a new national curriculum came into force in 2014 [4], [90], introducing a new subject, Computing, replacing the previous ICT curriculum. England is thus one of the few countries, which is not focusing on programming as an integrated trait, but rather on the larger discipline as its own subject.

The subject Computing contains three elements: computer science, information technology and digital literacy. The main aims are to ensure that all students: [4]

- can understand and apply the fundamental principles and concepts of computer science, including abstraction, logic, algorithms and data representation
- can analyse problems in computational terms, and have repeated practical experience of writing computer programs in order to solve such problems
- can evaluate and apply information technology, including new or unfamiliar technologies, analytically to solve problems
- are responsible, competent, confident and creative users of information and communication technology

The way in which these aims are to be reached differs at the four key stages, covering both primary and secondary education.

Computing at school (CAS, http://computingatschool.org.uk) is a community promoting computing at school. The community has (July 2016) over 23k registered users, nearly 80k discussion posts, over 200 local hubs and over 3600 teaching resources. CAS hubs are local communities of teachers and lecturers who wish to share ideas about teaching computing. The success of the CAS project has in part been credited to the hub network as local meetings reduce teacher isolation and increase teacher engagement. The teaching resources include lesson plans and guidelines for different levels, starting with Barefoot Computing (http://barefootcas.org.uk) and Teach Primary Computing (http://teachprimarycomputing.org.uk) for primary educators and QuickStart Computing (http://quickstartcomputing.org) providing support for both primary and secondary level. In addition, passionate teachers have also developed and shared teaching material (see, for instance, http://code-it.co.uk).

CAS also offers accreditation for Computing teachers, providing professional recognition by the British Computing Society. The certificate includes three parts: 1) reflection on professional development, 2) programming project and 3) classroom investigation. In addition, there is a Network of Teaching Excellence in Computer Science gathering professionals wanting to work together on these matters and providing widespread professional development. For example, the network includes CAS Master Teachers, who are experienced teachers with a particular passion for the subject and for supporting others.

C. Estonia

The Tiger Leap Foundation (TLF) is an Estonian organization, founded in 1997, aiming at developing the country's IT infrastructure and the quality of education with the help of technology [91]. As part of the results all Estonian schools were connected to the Internet, teachers were trained in computer usage and schools were provided with computers.

The ProgeTiger programme [92] was launched in 2012, aiming at introducing programming and robotics in education. The programme is carried out by the HITSA Development Centre of IT Education, funded by the Estonian Ministry of Education and Research. Other partners include the Estonian Ministry of Economic Affairs and Communications, as well as universities, the private sector and third sector institutions. aimed at pre-school, primary and vocational education and talks about digital competence as including both skills in using technology efficiently and responsibly, as well as understanding the essence of technology and being able to create technology.

According to HITSA [92], this competence is described as follows in the national curriculum for primary education: "the ability to cope in the technological world, understand technology trends and the connections between technology and other scientific achievements; to acquire technological literacy for age-appropriate, creative and innovative use of technology tools, integrating thinking with manual activities; to analyse opportunities and risks associated with the implementation of technology; to comply with the requirements for intellectual property protection; to solve problems by integrating thinking with manual activities and carry out ideas purposefully; to cope with household chores and eat healthy."

The ProgeTiger programme integrates three thematic fields — engineering sciences, design and technology and ICT — with different subjects. Engineering sciences include programming, electronics and robotics, while Design and Technology covers, for instance, 3D modeling, graphics, multimedia and animations focusing on user-friendly design. ICT focuses on the use of computers, networks and technology tools. To meet the goals of the programme, HITSA develops learning materials and offers professional development courses for teachers.

D. Finland

A new national curricula will come into force in Finland in 2016, covering both primary (grades 1–9) [93] and secondary (grades 10–12) [94] education. The curricula put increased focus on digital competence as an interdisciplinary trait throughout all grades. As for computer science content, the Finnish curriculum includes programming as an integrated element in primary education, while no computer science content is mentioned in the curriculum for secondary level.

At primary level, programming is mentioned explicitly in mathematics for grades 1–2, and in mathematics and craft for grades 3–9. In addition, programming is included as part of digital competence covering all subjects — hence, programming can be introduced in all subjects. In grades 1–6, teachers teach all subjects, which consequently means that all teachers are affected by the change. In grades 7–9, teachers teach 2–3 subjects, which may result in mainly those teaching mathematics and craft teaching programming.

In Finland, the National Board of Education, as well as the Ministry of Education and Culture fund projects, professional development and development programmes for supporting teachers in providing ways and materials for integrating programming in teaching and learning. In addition to local, specialized courses, online teacher training courses on programming were initiated in both Finnish and Swedish in 2015/2016, attracting a large number of participants. In addition to state supported initiatives, various activities are also provided by private actors, universities and organizations.

In 2014, the Ministry of Education and Culture published a call for specialization training programmes for in-service teachers. One of the accepted programmes was on teaching and learning in digital environments. This programme is offered, for instance by the University of Turku in Finland, including general courses on the topic, but also specialized courses on programming and making (http://www.utu.fi/fi/yksikot/ope-erko/digiymparisto/Documents/Ope-erko_digi_opetussuunnitelma%202016-2017.pdf).

E. New Zeeland

Computer science has been a subject of its own the last three years of high school since 2011. Prior to that focus was on teaching how to use computers [95]. "Programming and computer science" is a strand of Digital Technologies (http://www.nzqa.govt.nz/ncea/assessment/search.do?query=Digital+Technologies). It contains both programming and a broad range of computer science topics, including algorithms, human-computer interaction, artificial intelligence and computer graphics. These topics are not covered in depth, but rather cursory, giving students an understanding for what computer science is about. The topics are loosely based on the ACM/IEEE computer science curriculum [96]. Programming and computer science is also formally part of the National Certificate in Educational Achievement (NCEA), the main school-leaving assessment [95].

The progression within programming starts with introductory work in year 10, through the equivalent of an introductory university course in year 12 [95]. Year 10 focuses on tasks that involve input and output, and can be expressed as a single procedure program using sequence, selection and iteration, but only requires simple data (no arrays, lists, or structures). Year 11 focuses on tasks that involve multiple procedures and also use an indexed data structure. Year 12 requires the use of basic object-oriented programming concepts (classes and objects with encapsulation, but not inheritance) and a simple GUI implementation with event handling. For years 10 and 11, graphical programming languages like Scratch are allowed, while a text-based programming language is required for year 12. Many schools introduce text-based programming already in year 11, with Python as the most popular choice.

The new curriculum was introduced quickly leading to notable challenges related to preparing the teachers. Educating school management is also an ongoing challenge, and is an important element for the success of computer science in schools.To support teachers, a post-graduate distance course was developed to allow them to obtain a formal qualification in teaching computer science. The work on CS Unplugged [97] that started in the 1990s had developed experience in communicating computer science without using computers, and in environments where little time was available to learn programming [95].

To provide suitable teaching material, a free online open-source "CS Field Guide" was developed (http://csfieldguide.org.nz/en/about.html). It is an interactive site developed to provide information at the level required for the new computer science standards, including notes for teachers.

F. Norway

Norway has not yet introduced computing into their curriculum, but they will initiate a large pilot study in 146 secondary schools in fall 2016 (https://www.regjeringen.no/no/aktuelt/koding-blir-valgfag-pa-146-skoler/id2481962/). The schools will introduce programming as an elective for students in years 8–10. The curriculum (http://www.udir.no/globalassets/filer/lareplan/forsok/forsokslareplan-programmering-som-valgfag.pdf) states that the purpose is to teach programming including identifying problems, developing solutions, systematic debugging and improving the code, and documenting the solution in an understandable way. The students should learn at least two programming languages, and at least one should be text-based. An important motivation for the pilot study is to increase the interest in technology.

To train teachers a Massive Open Online Course (MOOC) has been prepared. To provide teaching material and also professional development an association called "Lær Kidsa Koding" has been initiated. The association provides extensive material online (http://kidsakoder.no/).

G. Poland

Computer science has been a subject in the Polish secondary education since the second half of the 1960s [100]. Starting in 1999, primary and second education consist of three stages.

In primary schools (grades 1–6) there is a stand-alone subject called computer activities. In grades 1–3, computer activities are supposed to be fully integrated with other activities like reading, writing, calculating, drawing, playing etc. At the next stages of education students are expected to use computers as tools supporting learning of various subjects and disciplines. The focus is on ICT.

In middle school (grades 7–9), informatics is taught for at least 2h/week during one year or 1h/week for two years. The curriculum contains algorithms, algorithmic thinking and problem solving with computers. Programming is not explicitly included, but most schools introduce it anyway. In high school (grades 10–12), there is one hour of computer science per week for one year, continuing on the content covered in middle school. Some schools offer a more rigorous computer science course as elective, and there is an optional final examination in computer science.

There is ongoing work on revising the curriculum to make it more unified [100]. In the proposal computer science is a compulsory subject in primary schools (grades 1–6, 1h/week for 6 years), middle schools (grades 7–9, 1h/week for two years), and high schools (grade 10, 1h/week). There will also be an elective computer science course in high schools (grades 11–12, 3h/week for two years) and high school students may graduate in computer science by taking the final examination. The unified aims are: Understanding and analysis of problems; Programming and problem solving by using computers and other digital devices; Using computers, digital devices, and computer networks; Developing social competences; and Observing law and security principles and regulations.

To support teachers there is a computer science education standards for teacher preparation, which is similar to the ISTE standards (http://www.iste.org). There is also a certification procedure, which evaluates a teacher's preparation for effective and successful teaching of computer science.

H. South Korea

The South Korean school system consists of 6 years of elementary school, 3 years of middle school, and 3 years of high school [98]. So called "computer education" started already in 1971. Since 2000, when the South Korean ICT infrastructure provided a computer to almost every classroom, content related to computers became nearly mandatory, with more than 34 hours of instruction in each grade. In middle and high school curricula the subject was designated as an elective. In 2007, "computer" was changed into "informatics" in the national curriculum, and the main focus has been on computer science principles and concepts.

A number of factors now seem to have worked together to make enrolment in informatics education in South Korea at middle and high school levels drop dramatically, from 80% to 23% and from 47% to 8%, respectively, between 2004 and 2012. Choi et al. [98] cite decreased time for elective subjects and the fact that various guidelines and policies concerning ICT education were repealed in 2008 as the main culprits.

In 2013, however, consensus concerning the importance of computer science education was reached, and, in 2018, a new curriculum will be introduced in South Korea [98]. It will include a compulsory subject "Informatics" in Middle School and a corresponding elective in High School. The curriculum will cover digital literacy, computational thinking and programming. Since the education system in South Korea is heavily textbook centered, new textbooks for the upcoming curriculum are currently being developed.

I. Sweden

The history of computer science in Swedish education has varied ([99].) Currently, computer science is not part of the curriculum for primary education, but an overview of ongoing activities related to computer science and computational thinking [29] indicates that the current curriculum provides many opportunities to include computer science content at school.

In 2015 the Swedish government gave the National Agency for Education (Skolverket) the task to develop a new curriculum for primary education (K–9) and to update the curriculum for secondary education (grades 10–12). They explicitly stated that the curriculum should strengthen pupils' digital competence and introduce programming. The National Agency for Education presented its almost final proposal (http://www.skolverket.se/skolutveckling/resurser-for-larande/itiskolan/lamna-synpunker-1.246272) in spring 2016, with the final proposal being submitted during summer 2016. Whether the government will accept the proposal and, if so, when it will come into force, is still unclear.

The proposal introduces a new general section on the importance of digital competence and understanding of digital technology for all. Changes are propsed to the course plans for Mathematics, Technology and Social sciences. Programming is introduced as part of the Mathematics curriculum, starting from giving step-by-step instructions as the basis for programming in grade 1–3, to how algorithms using sequence, alternative, repetition and abstraction can be created and used as part of programming in grade 4–6, to how algorithms can be created, tested and improved as part of programming for mathematical problem solving. Programming is also part of Technology, where focus is on controlling things using programming as well as developing basic understanding for computers and networks. The changes to Social sciences focus on digital competence and becoming a critical and responsible digital citizen. In addition, smaller changes are proposed in natural science subjects (use of simulations and modelling) as well as in crafts (extending the range of materials to also include modern technology). Finally, using digital technology and tools is made a requirement in several subjects.

Programming is already an elective in Swedish secondary school, but available to only a small selection of students in two programmes (natural sciences, technology). A current initiative aims at increasing access to programming and computer science for all students in secondary education.

The National Agency for Education has also received funding for national school development programs which will include in-service training for teachers. University teacher education faculties are responsible for pre-service training. Currently, most of these do not provide mandatory courses in digital competencies or programming. It remains to be seen how the proposed curricula changes will influence the education provided by these faculties.

J. USA

The education system in the United States is highly decentralized, and each state and school district may have their own curricula. At the same time there is an extensive push on the national level to introduce computer science for all (https://www.whitehouse.gov/blog/2016/01/30/computer-science-all) in the form of a $4 billion dollar initiative from President Obama.

There is a concerted effort by all major organizations (ACM, CSTA, Code.org, CIC, and NMSI) involved in computer science education to develop a Framework for K–12 Computer Science Education (https://k12cs.org/). They are asking big questions of the computing community: "What should all students know and be able to do in K-12 computer science? What does the community expect every student to learn in elementary school, in middle school, or by the time they graduate high school? And why? Underpinning this effort is our belief that computer science provides foundational learning benefiting every child." This work is about defining the basic expectations for what every student should have a chance to learn about K-12 computer science to prepare for the emerging demands of the 21st century, not just to major in computer science or secure jobs as software engineers.

The framework defines five concepts and seven practices. The concepts are: Devices, Networks and Communication, Data and Analysis, Algorithms and Programming, and Impacts of Computing. The practices are: Recognizing and representing computational problems, Developing and using abstractions, Creating computational artifacts, Testing and iteratively refining, Fostering an inclusive computing culture, Communicating about computing, and Collaborating around computing.

To support high school students that want to learn computer science a new advanced placement course call CS Principles has been designed (https://advancesinap.collegeboard.org/stem/computer-science-principles). The course is intended to give a broad understanding of computer science and is organized around seven big ideas of computer science: Creativity, Abstraction, Data and information, Algorithms, Programming, Internet and Global impact. The course is currently given for the first time and the first national exam will be held in May 2017.

Besides these national efforts there are many other initiatives (for instance, [101], [102]).

V. Publications on local K-12 computer science

Besides actual models for introducing computer science in K–12 education, we also reviewed conference proceedings to find information about to what extent such models are covered by the academic community. Table I lists, for each country and year, conference papers concerning the design of K–12 computer science curricula, whether computer science should be integrated or a subject of its own, or teacher training.

Country	What?	How?	Primary	Secondary
Australia	Digital Technologies	Own subject and integrated	Compulsory	Compulsory
England	Computing	Replace existing subject	Compulsory	-
Estonia	Programming (Technology & innovation)	Integrated	Compulsory	Compulsory
Finland	Programming (Digital competence)	Integrated	Compulsory	-
New Zealand	Programming and Computer Science	Own subject	-	Elective
Norway	Programming	Own subject	-	Elective
Sweden	Programming and Digital Competence	Integrated	Compulsory	Elective
South Korea	Informatics	Own subject	Compulsory	Elective
Poland	Computer Science	Own subject	Compulsory	Compulsory
USA	Computer Science	Own subject	-	Elective

Fig. 1. Overview of the different countries.

VI. Discussion

Table 1 shows a steady occurrence of publications related to the design of K–12 computer science curricula throughout the world. Nevertheless, the topics seem to have been more popular in 2005-2006, followed by a somewhat quieter time and a new upswing in 2012.

The education systems in the studied countries have notable differences, ranging from practical differences related to the age when children start school and the size of the school systems to cultural and historical aspects as well as the ways in which teachers are trained. These differences clearly make it somewhat difficult to find generalizable commonalities and lessons learned. Three common interesting dimensions are: what is being introduced? how? and at what level(s)? Additionally, for each level, there is a question of whether the content is elective or compulsory.

- What: Computing, Computational thinking, Computer Science, Digital competence, and Programming.
- How: Replace existing subject, New subject of its own, Integrated in several subjects.
- Primary/Secondary education: Elective or Compulsory.

The resulting overview can be seen in Fig.1.

By analyzing the situation in the countries we see that the trend is to introduce computing, programming and digital competencies in primary education. Some countries have already taken the step (England and Estonia), some are about to take the step (Finland, Poland and Sweden), while others are preparing for a potential introduction later (Norway and South Korea). Many countries have had computer science content as an elective in secondary education for quite some time (Poland, South Korea and Sweden), while others have introduced it quite recently (England, Estonia, New Zealand, and the USA). The next step is to make it either elective for a larger group of students or to make it mandatory.

When introducing new content in the curriculum, there is always the question of where to place it, what to remove and who should teach it. In England this was not a problem, as they already had a specific subject (ICT) that they could redesign into Computing, which then became a subject of its own with specialized teachers. Most countries are, however, introducing

TABLE I
PUBLISHED PAPERS AT SELECTED CONFERENCES FOR EACH COUNTRY AND YEAR.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Australia		[10]								[11]	[12]	
Finland		[13]										
Great Britain	[14]	[15]				[16]		[17]	[18]		[19]–[21]	
New Zealand						[22]		[23]	[24], [25]		[26]	[27]
South Korea		[28]										
Sweden											[29]	
Poland	[30], [31]			[32]					[33]		[34]	
USA	[35]		[36]		[37]	[38]–[40]	[41]	[42], [43]		[44], [45]	[46], [47]	
Austria	[48]–[52]	[53]					[54]	[55]				
Czech Republic								[56]				
Denmark									[57]			
France								[58]	[59]			
Germany		[60]			[61]	[62]		[63]	[64]			
Greece								[65]				
Hungary		[66]										
Israel		[67]					[68]	[69]	[70]			
Italy		[71]					[72]			[73]		
Lithuania	[74]	[75]		[76]								
The Netherlands				[77]					[78]			
Russia	[79]											
Switzerland							[80]					

computing by adding content to selected existing subjects or as a cross cutting theme throughout education.

There are many vocal proponents of having computer science as its own separate subject, and from a pure subject matter perspective this is likely to be the best approach. In an ideal world there would be room for the subject in the schedule with highly trained specialist teachers. However, due to practical constraints both in terms of limited school hours and the lack of highly trained teachers, many countries have chosen to introduce computer science as part of existing subjects.

There are some good arguments for doing this, besides the practical considerations. First, computing influences all subjects due to the digitalization of our society. Second, there is a need to develop teachers' digital competencies and make school more modern and relevant. If computer science is its own subject, it would be very easy for all other teachers to point their fingers on the computer science teachers to take care of the problem and then continue their practice as before. By encouraging more teachers to include aspects of computer science in their subjects, one can expect that they will have to develop their digital competencies. A risk, on the other hand, is that the quality of teaching of computer science will be diverse, based on teachers' interest in and time available for studying computer science themselves. A common struggle among all the countries is hence professional development and training for both pre-service and in-service teachers.

VII. CONCLUSIONS

The interest for computer science in school has never been as high as now. Many countries have or are about to introduce computer science in some form into their national curricula. At the same time the education systems differ widely, making it harder to compare and to learn from each other. This paper gives an overview of the approaches in 10 different countries. The general trend is to introduce computer science, often in the form of computational thinking, programming och digital competencies, in primary education while the trend in secondary education is to develop broader courses on computer science and its impact on society, which is in contrast to previously mainly having programming courses.

The studied countries either emphasize digital competencies together with programming or the broader subject of computing or computer science. Computational thinking is rarely mentioned explicitly, but the ideas are often included in some form. The most common model is to make it compulsory in primary school and elective in secondary school. A few countries have made it compulsory in both, while some countries have only introduced it in secondary school. The common challenges to all countries are to educate and keep good teachers with relevant knowledge and skills and to develop a suitable progression paired with teaching material throughout the education system.

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