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Implementability of computational thinking in Danish compulsory school mathematics – a survey conducted in a pre-implementation context

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This paper studies the implementability of computational thinking (CT) among mathematics teachers by studying their pre-implementation practices of teaching CT. Based on survey responses (n=67), we report on analyses of what CT Danish mathematics teachers teach in their mathematics classroom, and with what mathematical subject areas they combine it. The study finds that more than 2/3 of the population teach CT, and that CT is taught in a wide range of mathematical subject matter areas. This is surprising since CT is not a mandatory part of the current curriculum, but could be amplified due to selection-bias. These practices are different from previous research results that have found CT relevant in relatively few mathematical content areas. This indicates a need for near future implementation strategy for CT in Danish compulsory school mathematics to address CT in a way with clear relevance for mathematics.

Keywords: Implementation research, Computational thinking, Survey.

Introduction and background

In recent years, there has been a growing interest in computational thinking (CT) as a subject to teach in mathematics education. This is evident from curriculum revisions in e.g. Sweden (Swedish National Agency for Education, 2022), France (Modeste, 2018) and Norway (Andersen, 2022), in which CT (or closely related topics such as programming) has become a mandatory part of the mathematics curriculum. There are however significant variations among different countries in terms of what specific CT content has been included in the curricula, and with what and to what extent this new content has been coupled with mathematical content. In Sweden, programming became part of algebra, and computer simulations became part of statistics (Swedish National Agency of Education, 2022). In lower secondary school in France, algorithms and programming are part of the mathematics curriculum, but it is not explicitly connected to mathematical content (Modeste, 2018).

Currently, Denmark is on the verge of deciding how to implement CT in the compulsory school curriculum. In 2018, the Danish Ministry of Education launched a pilot project in which 46 schools implemented a new subject called technology comprehension (TC) with its own curriculum (Regeringen, 2018). The pilot project included four competence areas: digital empowerment, digital design and design processes, computational thinking and technological agency and tried out two implementation strategies, one in which TC was implemented in mathematics. In this latter strategy, six TC components were added to the existing mathematics curriculum: (1) digital design and design processes, (2) modelling, (3) programming, (4) data, algorithms and structures, (5) user studies and redesign and (6) computer systems. Similar to the case of France, the newly added TC content was not explicitly related to mathematics. The pilot project officially ended in 2022 and was evaluated

two times (halfway and at the end). The evaluation should inform a national implementation strategy, which still has not been disclosed. The general expectation is that the national implementation decision will include an integration of CT content in the mathematics curriculum, and Danish mathematics teachers are thus likely to face the task of teaching CT soon. Based on a survey of Danish mathematics teachers' self-reported practices of teaching CT in their mathematics classrooms, this paper discusses the implementability of CT in a Danish context. Inspired by work by Jankvist and Gregersen (2021), we refer to implementability in the sense of "how realistic and feasible it is for practitioners to implement an innovation" (p. 8). As argued in previous implementation research (see e.g., Koichu et al., 2019), successful implementation processes rely on compatibility between the innovation to be implemented and the existing practices of end-users. We believe that an important aspect of imminent implementation processes is to understand the current practices of the end-users. In this paper, we therefore study to what extent and how Danish mathematics teachers teach CT in their mathematics classroom by posing the following research question: *What CT content do Danish mathematics teachers currently teach, and with what mathematical topics do they combine it?*

To address this research question, we draw on Danish mathematics teachers' responses to a survey on their current teaching of CT in mathematics. In what follows, we briefly review literature on the relationship between CT and mathematical content as well as previous survey studies on mathematics teachers' teaching and conceptions of CT.

Related work

Since Papert (1980) introduced the term computational thinking, there has been a strong link between computational thinking and geometry, partly due to the emphasis on this mathematical topic in the book *Mindstorms* (Papert, 1980). Papert (1980) introduced a microworld called Logo, in which students could navigate a turtle via a notation that resembled natural language. In particular, Papert's (1980) book emphasized the relevance of Logo for geometry. Logo was however subsequently researched in relation to a number of different mathematical content areas. In 1997, Clements and Sarama reported on the progress of learning mathematics with Logo by summarizing research findings on the mathematical subject areas in which Logo could support mathematical learning. They found three main areas in which Logo was beneficial: 1) geometry and spatial intelligence, 2) number, arithmetic and algebra and 3) ratio and proportion. In terms of 1), Clements and Sarama (1997) argued that students construct initial spatial notions from actions and that this is supported in Logo since students program the turtle to move. Writing a sequence of commands in Logo to, for example, draw a rectangle "allows, or obliges, the student to externalize intuitive expectations" (Papert, 1980, p. 145). When the turtle executes this command, the rectangle becomes more open and accessible for reflection, since students can analyze the visual aspects of the rectangle and reflect on how they can build it from its parts (Clements & Sarama, 1997). In terms of 2), Logo did not support practices for arithmetic operations. However, it did provide a context with an authentic need for arithmetic. Clements and Sarama (1997) mention an example, in which students needed to determine the length of a bottom line in a tower they had constructed in Logo. These students determined the length of the line by adding the length of three horizontal lines, which they had constructed to build the top part of the tower. In that way, Logo provided a context in which students' arithmetic operations had a clear purpose. In terms of 3), Clements and Sarama (1997) found that when working on geometric

proportion tasks in Logo, students would formalize proportional relations algebraically as Logo programs and receive instant visual feedback on their mathematical intuitions.

In spite of the promising affordances of Logo, the program and the concept of computational thinking in mathematics never became mainstream (Resnick et al., 2009). Since, CT has re-emerged and has led to a number of recent studies in mathematics education research including surveys on mathematics teachers' conceptions of the topic. One of these is Misfeldt et al.'s (2019) study on Swedish mathematics teachers' conception of programming as part of the mathematics curriculum. This study found a generally positive stance among Swedish mathematics teachers in relation to programming as they agreed that their students benefit from their mathematical knowledge when programming. Moreover, the teachers reported that they believed their students could obtain a better understanding of mathematical concepts when programming and that they found it meaningful to integrate mathematics and programming in the same subject (Misfeldt et al., 2019). Similar findings appeared in the final evaluation survey from the Danish explorative project on implementing CT (Undervisningsministeriet, 2023), which reported that the teachers in the project generally viewed CT as a highly relevant topic to teach. These teachers also reported that they found it meaningful to integrate technology comprehension in existing subjects, particularly in science and mathematics.

In sum, the research outlined above indicates potential of CT for learning mathematics, and that mathematics teachers tend to have a positive stance towards teaching the topic in mathematics. In this paper, we aim to contribute to the existing body of knowledge by studying the practices of Danish mathematics in a pre-implementation context, where CT is not mandatory, but where there is a growing interest in the potentials of CT and the digital tools that support it.

Method

Our study draws on survey data collected January-April 2022 (see Tamborg et al., 2022) for a comprehensive account of the survey design). We sent this survey to mathematics teachers from Denmark, Sweden and England. In this paper, we draw on data from the Danish teachers (n=73). We initially distributed the survey to a random selection of 100 schools. Due to low response rates, we eventually distributed it on social media as well. This implies that we expect a selection bias due to teachers interested in CT being more prone to answer the survey. We excluded 6 respondents in the analysis, due to answering "don't know" to whether they used PCT in their teaching. The included respondents have a mean age of 46.4 with the population equivalent of 44.8 (Børne- og Undervisningsministeriet 2023). The students taught by the respondents are on average 11.8 years old with a range from 6.5 to 16. Most of the teachers allow (48) their students to access computers in all classes, while the rest (19) allow it sometimes. 52 of the 67 teachers have more than five years of seniority and three of the respondents had not received formal teacher training. Only six of the teachers reported that they were aware that the school they worked at had a strategy to implement CT.

Survey design and approach to analysis

Our analysis relies on question items that inquired the teachers about what CT content they taught in their mathematics teaching and in what mathematical subject matter areas they taught CT. An obvious challenge in a survey on CT is the fact that CT is an ambiguous term which is defined in a myriad of

ways. We chose to rely on a definition developed by Kallia et al. (2021), which reads as follows: “A structured problem-solving approach in which one is able to solve and/or transfer the solution of a mathematical problem to other people or a machine by employing thinking processes that include abstraction, decomposition, pattern recognition, algorithmic thinking, modelling, logical and analytical thinking, generalization and evaluation of solutions and strategies”. The respondents were introduced to this definition (translated into Danish) at the very beginning of the survey. The full survey is found here: doi.org/10.13140/RG.2.2.23419.18729

The items describing the CT content taught by the teachers were informed by Weintrop et al.’s (2016) taxonomy for computational thinking practices. Weintrop and colleagues (2016) distinguish four main computational thinking practices: (1) data practices, (2) modelling and simulation practices, (3) computational problem-solving practices, and (4) systems thinking practices. Each of these four practices is further described by 5-7 taxonomical levels. In the survey, we translated these practices and their taxonomical levels into questions for the teachers on what parts of computational thinking they taught. The teachers can select all the practices they apply for each CT type implemented. Further, the survey included questions on whether they taught CT with digital tools, analogue CT, programming or neither programming nor CT. If the teachers reported to teach CT and/or programming, our survey included a follow-up question in which the teachers were asked to report the specific digital tools they used. If the teachers reported teaching analogue CT, they therefore reported teaching the same practices as those in digital CT, but without the support of digital tools.

Our questions on the mathematical subject areas with which CT was combined relied on the framework for mathematical competencies (the KOM framework) (Niss & Højgaard, 2002). In this framework, Niss and Højgaard (2002) outline ten essential subject areas of mathematics: algebra, arithmetic, numbers, functions, statistics, probability, infinitesimal, discrete mathematics, geometry, and optimization. The survey also included a question on the degree to which they combine it with CT. The teachers also had the option to state that they did not cover the subject matter area in their teaching. To balance the variation with our number of respondents, we reduced the complexity in the analysis by regrouping the variable to contain a binary variable of whether the teachers taught the subject matter area and a binary measure of whether the teachers implemented CT in the subject area.

Our analysis includes results generated from three statistical analyses: 1) the type of CT taught by the teachers, 2) the distribution of the CT practices as reported by the teachers and 3) the co-occurrence between these CT practices and mathematical subject matter areas. Due to the number of respondents, the analyses are descriptive in nature and cannot claim statistical significance. Instead, the analysis is informed by investigating homogenous patterns across the graphical illustration of respondents.

Results

Figure 1 below illustrates the type of CT taught by the respondents. The figure shows that less than a third of the respondents reported not having taught CT as part of their mathematics teaching. Digital CT is most frequent taught by more than half of the population, closely followed by computer programming. Only 10 of the teachers reported that they teach analogue CT.

Figure 3. Combination of CT and mathematical subject matter area content taught by the teachers

Figure 3 shows the co-occurrence between CT practices and mathematical subject areas. The bars represent 3 types the number of teachers who reported teaching the subject area (the light grey coloured bar), the number of teachers who reported teaching the specific CT practice within that subject area (the solid-grey bar), and a dashed line which shows the number of respondents who uses the specific practice. The dotted line shows the highest possible number of teachers who use CT practices when teaching a specific subject area. These differ between the CT practices (as shown in figure 1), but to make a better baseline for comparison, they are visualized on the same y-axis from 0-40. Figure 3 shows that the data and modelling practices were frequent in the respondents' mathematics teaching, while complex systems practices were the least frequently taught. Across all 4 CT practices, discrete mathematics, infinitesimal mathematics and optimization are the least frequent mathematical subject areas that are combined with CT. These mathematical areas are however also the topics that the fewest of the respondents reported to teach in their mathematics classrooms. Except from these areas, there is an approximately equal distribution of all mathematical subject areas with which CT are combined.

Discussion and conclusion

As stated, CT is not a mandatory part of the Danish mathematics curriculum. It is therefore striking that more than 2/3 of the respondents reported addressing CT as part of their mathematics teaching. In some instances, there is however an overlap between the CT content the teachers reported to teach in the survey and that of the current Danish mathematics curriculum. For example, the Danish mathematics curriculum states that students after grade 9 (aged 15-16) should have “acquired skills to make use of digital tools for simulations in modelling processes¹”. This resembles Weintrop et al.’s (2016) second CT practice, namely modelling and simulation practices. The teachers’ most implemented CT practice is data practices, and their choice of CT practices expands what can be identified from the mathematics curriculum. Further, the digital tools used by the respondents go beyond specific mathematical tools and include CT- and programming-specific tools such as Micro:bit and Scratch. This indicates that the respondents at large covered CT and programming as extra-curricular dimensions of their teaching. Naturally, there is a difference in what aspects of CT and at what level of complexity it is possible to teach in with analogue tools. As pointed out, the analogue CT category in our survey is however the only difference from digital CT in the absence of digital tools – the core components are still different from what expected in the current curriculum. From an implementability point of view, this could witness a much higher level of maturity among the respondents than what is reasonable to expect. Hence, a natural question to pose is: what is the need of a national implementation decision on CT in the mathematics curriculum, if teachers already teach it at their own initiative? Koichu et al. (2021) defines implementation in mathematics education “an ecological disruption to a particular mathematics education system, through the gradual endorsement of innovation in conjunction with an action plan aimed at resolving what is perceived

¹ https://emu.dk/sites/default/files/2020-09/GSK_F%C3%A6llesM%C3%A5l_Matematik.pdf p. 9

as a problem by (at least some of) the stakeholders involved” (pp. 986). A curious characteristic of the respondents’ practices seen in the light of this definition is that they are *not* guided by an agreed upon action plan, and that they do *not* address an agreed upon perceived problem. The limited data in our study do not allow us to provide causal explanations. The results presented above show that teachers who report to teach CT in their mathematics teaching tend to apply it in almost every mathematical subject matter area that they teach. This broad application of CT does not reflect findings reported by Clements and Sarama (1997), who found potentials of Logo in only a limited number of mathematics learning. In this light, it seems clear that a near future implementation strategy for CT in Danish compulsory school mathematics should include a clearly defined action plan and address a problem with clear relevance for mathematics. While this seems obvious, previous national implementations of CT in mathematics education have not been accompanied by such plans and aims but have addressed more general societal needs for increased digital competencies (Tamborg, 2022).

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