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Towards designing a comparative survey for implementing PCT in Danish, Swedish, and English K-9 mathematics education

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This paper reports on the development of a survey tool to investigate how programming and computational thinking (PCT) is implemented in Denmark, Sweden, and England. The survey is targeted at mathematics teachers and aims to understand their enactment of PCT in their field and their perceived attributes of the innovation. Developing this kind of survey is difficult as implementation strategies differ significantly. This paper argues that one way to build a foundation for comparison is to inform its focus by utilizing 1) implementation theory and 2) innovation-specific theory.

Keywords: Computational thinking, design-based implementation research, implementing PCT in mathematics.

Introduction

During the last decade, an increasing number of countries have implemented curriculum revisions to include elements of programming and/or computational thinking (CT) in K-9 schools. These countries have adopted different approaches to this implementation process (Bocconi et al., 2016), which involve variations in the nature of the implemented innovation, the offered support strategies, the characteristics of the end-user, and the organizational and environmental factors surrounding the implementation process. While PCT as a compulsory school subject is not always explicitly linked to the mathematics curriculum, both researchers and practitioners in mathematics education acknowledge that there are potential synergies when integrating PCT within the subject. Despite this, previous research indicates that the establishment of meaningful synergies is far from a trivial endeavor (Misfeldt et al., 2019). At this point in time, mathematics teachers from many countries are likely to have encountered elements of PCT in their teaching; more than 50% of all math teachers in The International Computer and Information Literacy Studies' (ICIL) measurement of computational thinking reported an emphasis on computational-thinking-related tasks in their subject (Fraillon et al., 2020). ICIL's framework investigated information and communication technologies in schools across the subjects, including both explicit and implicit aspects, and it found similarities in the content, resources, methods to support learning, and priorities, despite rather different formulations of plans and curricula (Fraillon et al., 2020). Each of the nations did however focus more on computer and information literacy than on computational thinking. From an implementation perspective, this leaves us in a situation where it is still unclear how and to what extent experiences of teaching PCT and mathematics differ when situated in divergent contexts. This would be valuable in gaining an understanding of the implications of various implementation strategies for mathematics teachers' practices. Still, the differences that make comparisons interesting represent a challenge when

developing a research design. Although many nations have implemented an innovation, which can be labeled under the broad umbrella term of CT, there are substantial divergences in what aspects of the concept are emphasized. Moreover, national implementation strategies regarding PCT are often comprehensive and organized differently. These differences make it difficult to develop a design that is both broad enough to build a foundation for comparison and still sufficiently sensitive towards country-specific contexts. Previous research has studied teachers' conceptions of PCT in national contexts (Misfeldt et al. 2019) and across countries (Manila et al. 2014). However, this research mainly focused on mathematics teachers' ideas about PCT, while Manila et al. (2014) studied educators in all subjects. Additionally, none of these studies explicitly concentrated on implementation. This paper reports on our work of developing a questionnaire that enables us to find variations in how PCT and mathematics are enacted and experienced by teachers in three broadly different contexts. We chose Denmark, England, and Sweden for comparison as they have adopted distinct strategies for implementing PCT. Here, we will discuss how to design an implementation study that is sensitive to country-specific variations, creates meaningful survey items for educators in all nations to ensure reliability and validity (Wikman, 2006), and can thus provide a meaningful foundation for comparison. In this paper, we intend to spark a discussion about what properties we should expect from comparative implementation studies in relation to mathematics education. To engage in this debate, our starting point will have its basis in our reflections relating to developing a survey for mathematics teachers in Denmark, Sweden, and England on how they 1) teach mathematics and PCT and 2) what they see as the main difficulties and potentials of doing so. From an implementation perspective, our survey thereby specifically concentrates on what Century and Cassata (2016) refer to as the end-users' innovation enactments and their perceived attributes of the innovation itself. The overall aim is to address the following research question: *How can we develop a survey to compare mathematics teachers' enactments of PCT in mathematics education and their perceived attributes of the innovation in different national contexts?*

We begin the paper by outlining the situation in the three countries. Next, we describe the issues we encountered when developing a survey that can be both applied to the different situations in the countries and provide a meaningful foundation for comparison and the theoretical sources that we drew on to address these difficulties. Finally, we present how this was translated into a survey design and the limitations and strengths of this approach in terms of reliability and validity.

The situation in the three countries

As described in the introduction, Denmark, Sweden, and England have adopted different approaches to implementing curriculum revisions regarding PCT. In this section, we describe the nature of the approaches in the three countries and summarize their main differences from the point of view of implementation as well as investigate the relationship between PCT and mathematics.

Sweden

In 2018, the Swedish K-9 curriculum was revised as part of a national strategy to build students' digital competency. The rationale for this strategy was dual. First, the Swedish government highlighted that being digitally competent in the sense of understanding and mastering technology has become a prerequisite for being an active part of a democratic society, making it imperative.

Second, reports from the Statens Medieråd identified substantial differences in the digital habits and competencies of young Swedish people based on variations in gender, ethnicity, and demographic/socio-economic backgrounds. The national government referred to the increased focus on digital competency in compulsory schools as an approach to address this issue (Skolverket, 2018). This increased concentration on digital competency was cemented by revising the curriculum for several subjects in compulsory schools and by adding certain elements to legal documents, which re-establish the purpose of schooling in Sweden. Both initiatives aimed to make the responsibilities of Swedish schools clearer (Skolverket, 2018). This strategy led to revisions of all major subjects in schools (including mathematics, technology, civics, biology, chemistry, physics, Swedish/Swedish as a second language, and handicrafts), which were altered to include digital competency. In the context of mathematics education, this led to an innovation consisting of a revision of the curriculum, meaning programming was introduced as part of problem solving and algebra. The new programming component was thus embedded in the curriculum by rephrasing existing descriptions of the subject to integrate the skill. For example, in the case of algebra levels one to three, the curriculum specifies that students should learn “how unambiguous step-by-step instructions can be constructed, described and followed as a basis for programming” and that they should have knowledge of the “use of symbols in step-by-step instructions”. Meanwhile, in problem solving for grade levels seven to nine, the curriculum specifies that students should acquire knowledge of “how algorithms can be created, tested and improved in programming for mathematical problem solving”.¹

Denmark

Denmark is yet to implement computational thinking in the Danish K-9 curriculum. Nevertheless, mathematics does include many aspects of CT-related teaching, especially with regard to problem solving, modelling, and tools/aids. The related goals incorporate the following: “The student can plan and undertake problem-solving-processes” (problem solving), “The student can undertake modelling processes, including with the use of digital simulation” (modelling), and “The student has knowledge of different concrete materials and digital tools” (remedies)². However, these desired competencies have not been formulated as items specifically relating to PCT in the curriculum. From 2018–2021, a new subject entitled technology comprehension (TC) was implemented at 46 schools across the country as an experimental pilot project (Smith et al., 2020). The project included two implementation strategies, namely 1) implementing TC as a subject in its own right and 2) integrating it into other subjects (into mathematics in this instance). In both cases, TC was comprised of four areas of competency: digital empowerment, digital design and design processes, computational thinking, and technological knowledge and skills—including programming (Smith et al., 2020). The Danish Ministry of Education (UVM) also published a tentative curriculum with added TC learning goals (UVM, 2019). Although the new subject might forecast that an actual PCT-oriented subject is on its way into Danish schools, it has not yet been settled on as to how or when it will be fully implemented.

¹<https://www.skolverket.se/publikationsserier/styrdokument/2018/laroplan-for-grundskolan-forskoleklassen-och-fritidshemmet-reviderad-2018>

² https://emu.dk/sites/default/files/2020-09/GSK_F%C3%A6llesM%C3%A5l_Matematik.pdf

England

England was among the first countries in Europe to absorb programming into the curriculum in 2013/2014 as a mandatory subject in its own right called computing. A key attribute of this innovation is its emphasis on technical and computer science-related content. The curriculum thus states that the aim is to ensure that all pupils, among other things, can understand and apply fundamental principles/concepts of computer science, analyze problems in computational terms, evaluate and apply information technology (including in relation to new or unfamiliar technologies), and analytically solve problems. In this respect, the computing subject in England can be considered a simplified version of what is taught in computer science at a university level. These attributes of the innovation reflect that the computing subject in England is intended to address a challenge that is phrased differently compared to the Danish context. In the former nation, one of the main aims of implementing the new computing subject was to lay the stepping stones for creating a workforce with adequate competencies to teach the next generation of programmers. In England, teachers of the now defunct ICT subject were assigned the responsibility of teaching its new computing counterpart. These educators received no formal training on how to disseminate the new subject to students, and there were no central initiatives to develop teaching materials. According to Larke (2019), the rationale behind not developing such initiatives was to ensure teacher-based autonomy when using and developing the materials they found were adequate to meet the needs of the curriculum. Although the computing subject in England is not related to mathematics, there are several ongoing research projects that explore the potential synergies of integrating programming into it. One of these projects is Scratch Math³ which has developed a number of teaching materials that integrate mathematics and programming that are accessible to all teachers.

Theoretical background

As evident above, the implementation scenarios in the three countries differ in several ways, making it challenging to design a comparative research design that can adequately examine the three contexts. One particular challenge is that the implementation processes are comprehensive and organized very differently across the countries. To provide a solid foundation for comparison, it is thus important to ensure there is a theoretically delineated focus on the implementation process in which teachers are the appropriate respondents to answer the questions in the survey. To guarantee this, we informed the survey's implementation focus by drawing on research by Century and Cassata (2016) who developed an influential characterization of implementation research in education; they described it as both an inquiry into the innovation itself but also of factors that influence how it is enacted, the relationship between multiple innovations, and the outcomes of it. They outlined five key aspects of major importance for implementation in education, namely the characteristic of the individual user, organizational and environmental factors, implementation over time, implementation support strategies, and attributes of the innovation. Using Century and Cassata's (2016) wording, we were able to define our primary interest in the survey as trying to gain insights into 1) how mathematics teachers enact the innovation and 2) their perceived attributes of the innovation they enact. While

³ <https://www.ucl.ac.uk/ioe/research/projects/ucl-scratchmaths>

Century and Cassata (2016) argue for the importance of studying the innovation, they distinguish between its actual (or objective) characteristics and the perceived attributes by the end-users. In the survey, we focused on the latter. Although the innovation (PCT) is described in somewhat loose terms in the three countries concerned, the relationship between PCT in mathematics and PCT is relatively clear. We therefore believe that available policy documents provide sufficient information about the actual characteristics of the innovation. Moreover, the existence of loosely described curriculum innovations makes understanding teachers' enactments of them even more important. We will return to the implications of this choice in the discussion.

A second challenge relates to the fact that the innovation being implemented is similar in that it focuses on CT, yet it is outlined in significantly different manners within the curricula and policy papers across the three countries. Although the innovation in all three nations addresses what could be labeled as aspects of PCT, there are differences in terms of which parts of the broad concept of PCT are emphasized. This is problematic as we intend to quiz mathematics teachers from the three countries on what aspects of PCT and mathematics they combine by providing a number of pre-determined content areas of PCT and mathematics for the respondents to choose from. These content areas are thus at risk of either being too comprehensive (if they were to include all elements of CT from each country) or biased towards the context of only one of the nations. To address this, we informed our questionnaire by employing Weintrop et al.'s (2016) framework for computational-thinking practices in mathematics education, which was developed to provide teachers with guidelines on how they can assimilate CT into their mathematics teaching; it also specifies four main areas of CT: data practices, modelling and simulation practices, computational problem-handling practices, and systems-thinking practices. With regard to which content areas of mathematics teachers combine with PCT, we utilized the 10 subject areas described in the KOM framework that was developed by Niss and Højgaard (2002). They are numbers, arithmetic, algebra, geometry, functions, infinitesimal calculus, probability, statistics, discrete mathematics, and optimization (Niss & Højgaard, 2002). Drawing on these models, we developed questions that ask teachers which PCT/mathematics subject areas they combine in their teaching; at the same time, we were careful not to bias what we asked towards the situation in one of the countries. More generally, by informing our survey with these theoretical frameworks, we aimed to ensure alignment between the survey questions and variations in the innovation across the three contexts and saw to it that the survey includes questions for teachers to answer that provide insights into their enactment of the innovation and their perceived attributes of it. Below, we describe how we operationalized these guiding theoretical principles within concrete survey questions.

Designing a comparative implementation survey

The survey is organized into three main sections: a background section, a section on teachers' enactments of the innovation, and finally a section on their perceived attributes of it. In this paper, we have especially focused on the last two sections, which we describe below.

Items in innovation enactment and perceived attributes of the innovation

The first obstacle when developing survey items is adhering to the need to concentrate on specific aspects of the implementation process, which mathematics teachers can provide comparable answers

to (Wikman, 2006). As described, we define this focus as innovation enactment and perceived attributes of the innovation by drawing on Century and Cassata's (2016) research. Even though this provided a focal point for the differing innovations, to ensure the reliability of our survey items and thus the validity of our survey, we still needed to provide a foundation for comparison without being biased towards the context in one of the countries. As previously mentioned, we chose to employ a relevant framework by Weintrop et al. (2016) to ensure that the examined elements of PCT were based on generally accepted models. With regard to the areas of math content, we relied on the 10 subjects from the KOM framework (Niss & Højgaard, 2002).

The issue of potentially biasing the questions towards one of the countries' modes of implementation stems from the major differences in relation to the focus of the innovation. With the Swedish implementation, we would expect a high number of teachers working extensively with computational problem-handling practices due to the heavy emphasis on this in their curricula. On the other hand, with regard to Danish schools, we expect there to be a preoccupation with computational problem-handling practices but also with modelling and simulation practices as it is an explicit learning goal in mathematics (see the section on Denmark). As England has implemented programming as its own subject, it is still rather unclear to what extent teachers recognize their practices as computational thinking and what math-related subjects are connected to this. This is where the practices of Weintrop et al. (2016) become useful. As this CT definition has been developed for science and mathematics, we anticipate that teachers in all three countries will be able to recognize the four practices. When employing the country comparison by ICIL (Fraillon et al., 2020), we also expect there to be some similarities between the practices and context areas, even though the innovations are rather different. Using the more fine-grained sample of 10 math subjects, we are also equipped to enable a comparison of how mathematics teachers enact PCT in their educational activities and to ascertain to what extent the different practices highlighted by Weintrop et al. (2016) are signified. This construction of items not only allows us to look at what CT-related practices educators employ in their teaching but also to investigate what subjects in the math field they are coupled with. This facilitated our investigation into the different practices that are utilized across countries and made it easier to look into the relationship between the innovation and the practices themselves. In the questionnaire, we thus asked teachers if they include programming and computational thinking via each of the four practices described by Weintrop et al. (2016): "One can work with programming and computational thinking in different ways. To what extent is working with data practices part of your teaching?" If teachers reply that they include it to some or a large extent, we then ask which of the ten outlined content areas from the KOM framework that they are coupling the PCT practices with.

After forming the item construction of PCT practices and math subjects, we created a framework for comparing innovation enactments instead of the innovation itself. As an add-on to that, we aimed to compare teachers' perceived attributes of the innovation, both across country-specific innovations and the enactments by teachers. With regard to the perceived attributes of the innovation, we drew on a survey made for Swedish teachers (Misfeldt et al., 2019), yet we excluded questions that were too strongly influenced by the Swedish implementation of PCT into the math subject. The survey addresses teachers' perceived attributes of the innovation by including relevant questions, such as those relating to educators' experiences of the integration of PCT and math (e.g., "To what extent do

you agree with the following statement: Teaching programming supplements math teaching to a large extent”), how teachers experience programming as it relates to the enactment of the praxis (e.g., “My students are using their math capabilities when they are programming”), and finally the relationship they perceive between math and programming. In sum, the survey described above allows us to inquire about what aspects of PCT and mathematics educators in the three countries combine in their teaching and their experiences of doing so. We expect that the survey will enable the gathering of valuable insights into the different ways teachers navigate and experience teaching PCT and mathematics in the three contexts.

Discussion and conclusion: Comparative implementation studies in mathematics education

There are variances in how Danish, Swedish and English mathematics educators combine their subject and PCT within their teaching; their experiences of doing so are also contextualized by significantly different implementation strategies. This is exactly why a comparative investigation is interesting. Although our development of the survey tool described here is still at an early stage, we believe that our approach could provide inspiration for how to conduct comparative implementation studies within mathematics education. Our survey design is informed by two main types of theoretical frameworks: one is a theory that is specific to the innovations that are being implemented and the other relates to implementation research. We chose to inform our survey in line with these theoretical resources to address the concrete challenges we encountered. This relates to the need for a delineated focus on certain aspects of the implementation process (as opposed to the entire thing) and finding ways of developing questions for the teachers that were not biased towards one of the three countries; this would ensure the reliability of the survey items and thus the validity of our questionnaire. Furthermore, adhering to these models enabled us to compare similar enactments across contexts and their correlation to perceived attributes of the innovations. By focusing on innovation enactment and the perceived attributes of the innovation, we have to assume to some extent assume that we have an understanding of said innovation and the related implementation strategies in the three countries. This assumption is based on the fact that both the curriculum revisions and the relationship between PCT and mathematics are well-described in policy documents in all three nations. However, the delineated focus on enactment and the perceived attributes of the innovation come at the cost of gaining insight into other, potentially equally important aspects of the implementation processes. This choice mirrors our primary interest in understanding the daily practices of mathematics teachers with regard to what they do and how they experience their practices of combining PCT and mathematics. Fully addressing all aspects of the implementation in detail would require other respondents to partake in the survey (managers, supervisors, municipal staff, etc.) and a much larger population to gain significant results into national variations and stabilities. Since policy documents provide rich descriptions of the implementation processes that are sufficient to pinpoint substantial differences, we believe that understanding mathematics teachers’ enactments and perceived attributes of the innovation across these countries can provide important indications as to how such strategies are received by the end-users. Although our survey has not yet been tested, we believe that this work deals with an issue that has not been addressed explicitly in implementation research within mathematics education, specifically comparative implementation research in relation to mathematics education. We hope that

the work reported here can spark interest, which will then lead to further engagement in more systematic discussions about this matter.

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