From policy to resources: programming, computational thinking and mathematics in the Danish curriculum

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This article investigates the relations between mathematics and programming and computational thinking (PCT). In scholarly knowledge, PCT is juxtaposed as an aid to mathematical problem solving, but also integrated as a collection of practices common to both domains. This knowledge is being turned into curriculum and teaching resources developed for Danish compulsory schools (students aged 6–15), in the context of a pilot project to embed a new technology comprehension subject into mathematics. In the curriculum, PCT is being juxtaposed to mathematics. The teaching resources are predominantly integrated, but lacking connections to mathematical problem solving and modelling. These misalignments are both missed opportunities and a leeway for a cautious integration in teaching practice.

In recent years, we have seen a renewed international interest in how programming and computational thinking (PCT) can be converted into teachable competencies across primary, secondary and tertiary education levels (Bocconi, Chioccariello, Kampylis et al., 2022). In many countries, this has led to curriculum revisions, in which PCT either has been implemented as a new independent subject (e.g. the case of England; Department of Education, 2014) or as integrated into other subjects (e.g. the case of Sweden, see Heintz et al., 2017). When PCT is integrated into existing subjects, mathematics is often argued to be a relevant site to which these new PCT components should be added, because computer science and mathematics have shared foundations in logic and proof, and have formal means to model situations from other disciplines (Modeste, 2016; Gadani-dis et al., 2017). Moreover, when computational thinking was introduced by Papert (1980), it was mainly described as a new and efficient way for students to learn mathematics.

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There are, however, substantial differences in how PCT is integrated into mathematics across different Nordic countries (Bocconi, Chioccariello & Earp, 2018; Helenius & Misfeldt, 2021). This is evident in terms of whether there is, in fact, a relation between PCT and mathematics in curriculum revisions, what PCT and mathematical content are connected, and to what extent such links are explicit (Misfeldt et al., 2020). Moreover, research shows that teaching materials do not necessarily comply one-to-one with what is stated in the curriculum (Bråting & Kilhamn, 2022). The envisioned integrations between mathematics and PCT as they are described in both curriculum documents and in teaching materials are important to understand since they are likely to play a significant role in mathematics teachers' practice. This is particularly the case since PCT is new and unfamiliar to many mathematics teachers (e.g. Misfeldt et al., 2019; Nordby et al., 2022). Previous studies have either focused on describing the relationship between PCT and mathematics at the ministerial guidelines level (e.g. Helenius & Misfeldt, 2021; Misfeldt et al., 2020) or in curriculum material developed to support teachers in adopting new PCT elements in the mathematics curriculum (e.g. Bråting & Kilhamn, 2022). In this paper, we investigate both the prescribed relation between PCT and mathematics at the curricular level in the context of Denmark.

Our outset is a recent pilot project in which a new subject called *technology comprehension* (TC) was implemented at 46 schools across the country. This pilot project involved the development of a new mathematics curriculum to include TC, as well as a number of teaching resources to support mathematics teachers in teaching the new TC components as part of mathematics. It is this curriculum and the teaching materials that constitute the empirical basis of this study. However, we limit our analysis to investigating the envisioned relations between the TC competency areas of *modelling*, *programming*, and *data*, *algorithms and structuring*, thereby leaving out digital design, and design processes; and user studies, and redesign. Our reason for this choice is that these two latter PCT competency areas are unusual components in an international context, which have no immediate relation to mathematics.

We analyse these data from the perspective of the anthropological theory of the didactic (ATD). More specifically, we draw on the notion of external didactical transposition to describe the new TC curriculum and the mathematical curriculum resources developed to integrate mathematics and TC. We begin the paper by briefly outlining existing research on the relation between PCT and mathematics in curriculum documents and resources, and we position our contribution in relation to this body of knowledge. Next, we describe our theoretical framework and the empirical foundation in greater detail before we present the results of our analysis. We conclude the paper by pinpointing the interrelation between mathematics and PCT in the curriculum and the tasks developed to accompany the curriculum and by discussing potential implications.

Related Work

As stated above, this paper studies the relation between PCT and mathematics in the Danish mathematics curriculum and teaching resources developed to fit the curriculum. In recent years, we have begun to see an increased interest in these matters in the international literature. The literature in this area is however still sparse, since little time have passed since such teaching resources have been published. In this section, we begin by reviewing studies that address the scholarly aspects informing PCT as part of mathematics education curricula and resources. Next, we review literature that specifically studies the relation between mathematics and PCT from an ATD perspective, since this is the theoretical approach on which we draw in this paper. We conclude the section by situating the contribution of this paper in relation to existing work.

A recent study that have investigated curriculum material that integrate PCT and mathematics is that of Bråting and Kilhamn (2022). Their study concerned Swedish mathematics textbooks and set out to investigate programming and mathematics concepts and programming actions in 390 tasks. Although these authors exclusively studied textbook material, they noted a disconnect between how programming in mathematics is described in the curriculum and how it is integrated into the tasks. To ”follow a procedure” is by far the most frequent while creating algorithms is at the core of the curriculum for algebra in grades 4–6 and 7–9 and of problem solving for grades 7–9. Tasks more often connect to geometry or arithmetic (Bråting & Kilhamn, 2022), even though programming is described as part of algebra (Swedish National Agency of Education, 2018). Furthermore, Bråting and Kilhamn (2022) suggest that curriculum materials do not necessarily comply fully with the curriculum. Our research questions aim at closing these gaps and shedding light on how policy decisions manifest in concrete materials. Since few mathematics teachers are trained to teach PCT, these resources are likely to play a significant role in mathematics teaching.

Another branch of research in this area has set out to study the relation between mathematics and PCT in mathematics curricula or resources from a theoretical framework similar to that of this paper, namely that of ATD. Because of the relative novelty of the inclusion of PCT in school mathematics, these are, however, recent and few. Modeste (2018) reports a study drawing on ATD's praxeologies and the external didactical transposition. France had included informatics or computer science in different ways since the 1980s (Gueudet et al., 2017), which allowed Modeste to conduct his analysis with a historical sensibility. One key contribution of this study is to draw upon specific epistemological consideration of the relationship between mathematics and computer science (Modeste, 2016), namely: (1) foundations; logic and proof; (2) continuity and interfaces; (3) computer-assisted mathematics and experimental dimensions; (4) modelling, simulation, and relation with other disciplines.

There are a few comparative studies on the didactical transpositions of making programming or algorithmics part of the official curriculum and accompanying resources, following an ATD approach. Modeste and Rafalska (2017) illustrate the influence of institutions, traditions and history in the inclusion of algorithmics in France and Ukraine. In the former, algorithms are part of mathematics, whereas, in the latter, it is a subject in itself. Helenius and Misfeldt (2021) show that the Swedish revisions of the mathematics curriculum mainly concerned a transposition of programming into mathematics. In contrast, the Danish transposition concerned a much broader area of technology comprehension, drawing on knowledge from not only computer science but also sociology and ethics. Their study also shows differences in the extent to which curricula in the two countries specify an explicit relation between programming/TC and mathematics. These studies also include analyses of the internal didactical transposition. The analyses at this level mainly function as exemplary tasks that illustrate the two different external didactical transpositions. The benefit of this is that they are able to display how different curricular priorities and approaches manifest in concrete implications for curriculum materials.

Building from Helenius and Misfeldt (2021), Tamborg et al. (2022) took a closer look at the external didactical transposition of PCT into the Danish mathematics curricular guidelines. Their study takes a more comprehensive and structural approach, revealing that transposed TC knowledge has no immediate relation to definitions in the literature. More importantly, TC competencies are barely juxtaposed to mathematics, leaving most of the responsibility for integrating these domains coherently to teachers and material developers. We contribute to this work by systematically investigating both curriculum, tasks and the relation between mathematics and PCT in these data sources.

Theoretical Framework

ATD has been developed as an epistemological perspective of the teaching and learning of mathematics (Chevallard & Sensevy, 2014). It focuses on the nature of mathematical knowledge regarded as a human activity, and how it is disseminated and taught (Bosch & Gascón, 2006).

Although ATD commonly addresses the nature of mathematical knowledge within the discipline, many studies have taken a bi-disciplinary scope, such as the combination of mathematics and history (Hansen & Winsløw, 2010) and mathematical modelling in scientific contexts (Jessen & Kjeldsen, 2021) and engineering problems (Schmidt & Winsløw, 2021). Addressing a diversity of domains calls for specific attention to the level of coordination between the elements from different sources. The aforementioned coordination of multidisciplinary elements can happen on different institutional levels, be they academia, policymakers, teachers and students (Schmidt & Winsløw, 2021).

On those grounds, the theoretical element we draw from ATD is the didactic transposition (Bosch & Gascón, 2006), which refers to the processes by which scholarly knowledge is transformed into something taught and learned. Two main such processes can be identified: the external didactic transposition, from scholarly knowledge to that which is to be taught, and on the internal didactic transposition, from knowledge to be taught to teaching practice. This framing "underlines the institutional relativity of knowledge" (Bosch and Gascón, 2006, p. 56), acknowledging that these processes are determined by institutions. Scholarly knowledge is determined mostly by academic and professional institutions who produce and use the knowledge. The knowledge to be taught is determined by the myriad of institutions that configure the educational system and society or *noosphere*. The knowledge that is actually taught and learned is determined by particular classrooms and communities of study.

At the time of writing this article, TC has not been not implemented in the compulsory Danish educational system, and therefore, little can be said about classroom practice. Our study focuses on knowledge to be taught as depicted in the new curriculum and accompanying teaching resources. We thus focus on the external didactic transposition to address the following research questions.

> RQ1: What is the relation between mathematics and PCT in the external didactical transposition when focusing on the newly developed curriculum to integrate TC and mathematics?
>
> RQ2: What is the relation between mathematics and PCT in the external transposition when focusing on the teaching resources developed to accompany the newly developed curriculum?

Method

Addressing the research questions requires scrutinising the interplay between PCT and mathematics as part of scholarly knowledge and comparing it with how Danish curricular guidelines and available teaching materials go about it. As a point of departure, we mirror the approach taken by Jessen and Kjeldsen (2021). To study the external didactic transposition of mathematical modelling in scientific contexts, they applied the same categories to analysed selected examples from 20th-century scientific developments, ministerial guidelines excerpts, teaching materials and exam tasks. In our study, we aimed for a systematic approach to describe the knowledge at these levels. Below, we describe the data sources on which we draw and how we approached the analyses of these sources through the lens of two categories: the extent of integration or juxtaposition of PCT and mathematical knowledge, and a characterisation of integrated subject-matter areas from each domain, when applicable.

Data Sources

In their study, Smith et al. (2020) describe how TC is the result of a participatory endeavour involving a broad diversity of societal actors, with their corresponding perspectives and agendas. Helenius and Misfeldt (2021) point out; in particular, that in Denmark as it is in Sweden the integration of PCT into mathematics requires the mobilisation of knowledge from several domains, including the humanities, the technological industry and computer science, among others. Therefore, elements of PCT cannot be mapped directly from computer science as a scholarly discipline, let alone when intertwined with mathematics as a domain of knowledge.

Our basis for portraying scholarly knowledge relies on research that has dealt with this problem, by investigating the interplay between PCT and mathematics in industry and academia. Specifically, we draw on one recent and prominent study by Kallia et al. (2021), who aimed at characterising computational thinking in mathematics education. This choice is without loss of generality, since they first conducted a systematic literature review selecting 56 papers for full screening. This pool includes other prominent studies that, aside from their own literature reviews, have relied on a variety of documents released by educational policymakers and appropriate professional organisations (e.g. Pérez, 2018), and observations and interviews with mathematicians, computer and natural scientists (e.g. Weintrop et al., 2016).

Aside from the literature review, Kallia et al. (2021) refined and validated their characterisation through a Delphi study (Vernon, 2009), in which experts in mathematics and computer science answered three open-ended questions:

> (1) What characterises computational thinking in mathematics education?
>
> (2) What are the common aspects of computational thinking and mathematical thinking?
>
> (3) Which aspects of computational thinking can be addressed in mathematics instruction? (Kallia et al., 2021, pp. 171–172)

We narrow down to the insights gained from the first two questions, which aim at illustrating how PCT is currently part of mathematics education (1) and its commonalities with mathematical thinking (2). Question 3 is more aspirational and is out of the scope of scholarly knowledge.

Within the knowledge determined by the *noosphere*, we draw upon a revised mathematics curriculum and curriculum materials developed as part of a pilot project in Denmark that implemented the new TC curriculum in Danish schools. The pilot project was launched in 2018 by the Danish Ministry of Education, in which 46 schools across the country were to implement this new subject. The pilot project sought to gain initial experiences with two different models of implementing TC to systematically research the effects of these approaches and, ultimately, inform a future, national-scale curriculum revision (BUVM, 2021b). The two strategies were 1) technology comprehension as a subject and 2) technology comprehension as an integrated part of existing subjects, such as Danish, mathematics, social sciences, science, physics/chemistry, craft and design, and the arts (BUVM, 2018). Both implementation strategies began with a curriculum, which was developed as an initial part of the project. Moreover, it was decided that both implementation strategies should address the same curriculum components and that the curriculum for a subject in its own right should be developed first (Tamborg, 2022). Afterwards, the individual components of this curriculum were then distributed among the subjects into which it should be integrated. This curriculum was developed by an expert writing group, which developed a purpose declaration for technology comprehension and described four competency areas that it should address. These four competency areas were as follows:

> *Digital Empowerment*: the critical and constructive exploration and analysis of how technology is imbued with values and intentions, and how it shapes our lives.

> *Digital Design and Design Processes*: the ability to frame problems within a complex problem area and, through iterative processes, generate new ideas that can be transformed into form and content in interactive prototypes.
>
> *Computational Thinking*: the ability to translate a complex problem into a possible digital solution, and the abstraction of phenomena and relationships in the world and the computer's ability to process this information.
>
> *Technological Agency*: the ability to understand and use digital technology as a material for developing digital artefacts.
>
> (Smith et al., 2020, p. 150)

For RQ1, we analyse the official curriculum published for TC embedded in mathematics. This curriculum includes the four competence areas described above, further defined by 3–5 subject matter areas presented as pairs of skillsets and knowledge. These competency areas were then added to the otherwise maintained mathematics curriculum. The previous mathematics curriculum was organised as a description of competence goals organised into four competence areas: (1) mathematical competencies (see Niss & Højgaard, 2019); and subject-matter areas, (2) numbers and algebra, (3) geometry and measure, and (4) probability and statistics. In the experimental version of the curriculum, TC was added as a fifth competence area (see table 1).

Table 1. *Overview of how TC was added to the description of the mathematics curriculum for Danish K–9*

Competence area	Skillset and knowledge goals
Mathematical competencies	Description of six competencies: problem handling; modelling; reasoning and thinking; representation and symbol treatment; communication; aids and tools
Algebra and numbers	Description of five areas: numbers; calculation strategies; equations; formulas and algebraic expressions; functions
Geometry and measurements	Description of three areas: geometric properties and relationships; geometric sketching; placement and movements; measurement
Statistics and probability	Description of two areas: statistics, probability
Technology comprehension	Description of six areas of comprehension: digital design and design processes; modelling; programming; data, algorithms, and structures; user studies and redesign; computer systems

In the case of the mathematics curriculum, six TC components were integrated: digital design and design processes; modelling; programming; data, algorithms and structures; user studies and redesign; and computer systems. This is illustrated in table 2, below.

Table 2. *The six TC components related to the mathematics curriculum for Danish K–9 (our translation from Danish)*

TC components	Skillset	Knowledge
Digital design and design processes	The student can design digital artefacts through an iterative design process that will benefit the individual, the community and society.	The student has knowledge about complex problem solving and iterative design processes.
Modelling	The student can construct and act on digital models of the real world and assess the range of the model.	The student has knowledge about how models of the real world can be used to describe and treat this.
Programming	The student can modify and construct programs for solving a given task.	The student has knowledge about methods for stepwise development of programs.
Data, algorithms, and structures	The student can recognise and utilise patterns in the structuring of data and algorithms with a departure point in specific problems.	The student has knowledge about patterns in structuring data and algorithms.
User studies and redesign	The student can plan and carry out investigations of users' perspectives and applications of digital artefacts.	The student has knowledge about users' perspective and application of digital artefacts.
Computer systems	The student can assess different computer systems' possibilities and limitations.	The student has knowledge about how number systems, encryption mechanisms, and network protocols affect the basic construction and mode of operation of computers and networks.

As described, our analysis exclusively focuses on the PCT aspects of the TC curriculum, leaving out digital design and design processes, user studies and re-design, and computer systems.

To address RQ2, we draw upon 18 teaching resources designed for the pilot study in grades 1–9. These resources have been developed to support the integration of TC into mathematics teaching and are publicly available online[1]. The materials include explicit declarations of what mathematical competencies, mathematical subject matter areas and

TC competencies and sub-areas they combine. A full overview of how these competencies are combined throughout the sequences is available in table 3.

Table 3. *Overview of the available teaching materials and the content from mathematics and TC they address*

	Area	Mathematics			Technology Comprehension					
Grade	Course title	Numbers and algebra	Geometry and measure	Statistics	Digital design and design processes	Modelling	Programming	Data, algorithms, structuring	User studies and redesign	Computer systems
1	What can a robot do?		●				●			
1	Polygons' geometrical properties		●				●			
2	Design the class's new clock		●		●					
2	Concept of chance			●			●		●	
3	Descriptive statistics with help of aliens			●		●			●	
3	Design and re-design of containers	●	●		●	●				
4	Robots and trajectories		●		●		●			
4	Play yourself healthy	●		●			●	●	●	
5	Next steps with micro:bit	●		●	●	●	●	●	●	
5	Red ears in the common room	●					●	●		
6	Can you play yourself skilled in mathematics?	●					●	●	●	
6	Safety in the local community	●			●		●	●	●	
7	WEB 3			●					●	●
7	Packaging design and development		●	●	●					●
8	Statistics with bias			●				●		
8	Update dice			●			●	●		
9	Can I count on the machine?	●					●	●		
9	How does a computer "think"?	●						●		●

The overview in table 3 shows how these courses aim at teaching mathematics and TC, and eventually more than one sub-area of each are involved, marked with dots. As the courses entitled ”Design the class’s new clock”, ”WEB 3” and ”Packaging design and development” do not address PCT content – marked with grey shading – , these are not included in our analysis. Consequently, our analysis of tasks concerns 15 didactical sequences. The sequences are structured into three phases: introduction, construction and challenges, and outro. Within each phase, activities take the form of feedback and subject (*faglige* in Danish) loops (BUVM, 2021a). However, the materials signpost tasks with different names, such as activities and concrete challenges. We therefore designate the units of analysis as each task included in the 14 aforementioned didactical sequences, for a total of 214 tasks.

Approach to analysis

As described above, we draw upon different data sources to address our research questions that are different in nature. Accordingly, we processed and analysed them differently. However, addressing the external didactic transposition means investigating the coherence between knowledge defined by different institutions using a common framework (Jessen & Kjeldsen, 2021). Our framework consists of two overarching dimensions:

1. *Juxtaposition versus integration*. This dimension follows the epistemological consideration of *continuity and interfaces* (Modeste, 2016), that is, the fact that ”the frontier between Mathematics and Computer Science is impossible to draw” (Modeste, 2018, p. 3). We aim at laying out the extent to which mathematical and PCT knowledge are displayed separated or combined.

2. *Co-occurrence of PCT and mathematics*. Within the extent to which mathematics and PCT are integrated, we take a deeper look into how they do so. This dimension relates to two other epistemological considerations (Modeste, 2016): *computer assisted mathematics and experimental dimensions*, and *modelling, simulation and relation with other disciplines*. These aspects account for more specific interactions between computational and mathematical elements. That is, we address which competencies and subject-matter areas from each domain are most commonly integrated.

In what follows, we elaborate on our approach for doing so for each source.

Literature analysis

Kallia et al. (2021) reported aspects that characterise PCT in mathematics education (question 1) and that are common to mathematical thinking (question 2). They displayed the percentage of participants' responses containing these aspects, and reduced the list based on a statistical analysis. For example, although some respondents mentioned the use of digital technologies to solve problems, this aspect did not generate consensus, since many academics respondents view PCT as a way of thinking detached from computer devices and put forward the value of unplugged or analogue tasks (Caeli & Yadav, 2020; Li et al., 2020). We first narrow down our analysis to aspects that reach consensus. From there, our approach consisted of identifying the extent to which these aspects are depicted in a well-defined divide between PCT and mathematics (juxtaposition) or not (integrated). For example, the *abstraction* aspect reaches a consensus as being part of mathematical and computational thinking, which points to integration. At the same time, in the bigger picture, *abstraction* is depicted as a computational thinking process that aids mathematical problem solving, signalling juxtaposition. For the co-occurrence dimension, we inquired on which specific elements from PCT and mathematics are combined when integrated. For example, *logical thinking* appears as a common substantial element which may indicate the intersection between computer science and propositional logic. However, as Selby and Woollard (2013) argue, logical thinking is seldom defined and broader than formal logic. In most cases, coding co-occurrence is speculative rather than explicit in the study.

Curriculum analysis

Our analysis at the level of curricular guidelines concerns mainly how the PCT components structurally relate to mathematics, building on our previous work (Tamborg et al., 2022). We applied the two dimensions of our analysis in two ways. First, we study how the newly added PCT elements are structurally positioned in relation to the existing mathematical content in the curriculum, that is, how PCT in the curriculum goals relate to the remaining mathematical content in the curriculum. This latter approach allowed us to infer whether PCT and mathematics were juxtaposed or integrated. Second, we investigated how the added PCT curriculum components are described in the curriculum, and how these descriptions relate to mathematics. Here, we focus on the skillsets and knowledge as they are described in the curriculum goals for programming, modelling, data, algorithms and structuring and computer systems. In particular, we study how the PCT goal descriptions relate to mathematics to inform the external didactical transposition when focusing on the curriculum. For example, the TC curriculum includes the competency area *data, algorithms and structures*. Its associated skillset description specifies that students should be able to ”recognise and utilise patterns in structuring of data and algorithms with a departure point in specific problems”. We first identified that the goals for students' skills were separate from the existing goals for students' mathematical skills, as oposed to revising mathematical skills to integrate the recognition and use of such patterns. In the second dimension, we identified that patterns, data and algorithms resembled mathematical content represented in other aspects of the existing mathematics curriculum such as statistics.

Task analysis

To analyse the tasks, we expand the schemes developed by Bråting and Kilhman (2022) and Elicer and Tamborg (2022). These analyses involved identifying and distinguishing between mathematical and PCT concepts and actions. Respectively, these categories account for the know-what and the know-how involved in the learning activities. The coding scheme of the 214 tasks is as follows.

Mathematical and PCT concepts are coded as depicted explicitly in the tasks. Implicit or potentially exploitable ideas are not coded. For example, the course ”Red ears in the common room” declares the algebraic concept ”variable” in the briefing and the evaluation. However, no signposted task that students ought to face makes mention of it, and thus it is not coded. We identify mathematical concepts as those belonging to traditional school mathematics, whereas PCT concepts are those that convey a computational idea. In case of ambiguity, the context of the task provides guidance. For example, the concept of ”model” appears in the course ”Design and redesign of containers”, not as a mathematical model but as a physical 3D-printed prototype and as a computer (TinkerCad) model. In that context, it is then coded only as a PCT concept. A concept can be coded in both domains, as is often the case with ”data”.

PCT actions are mapped into the following categories: follow (stepwise instructions), figure out (a pattern), debug (or fix), program (or create), explain, envisage (or predict), and bridge (to mathematical concepts). Bråting and Kilhamn (2022) proposed this analytical tool by adapting it from Brennan and Resnick (2012) and Benton et al. (2016, 2017) for task analysis of Swedish textbooks. In our coding process, we allow PCT actions to be coded in a task even if no PCT concepts are, since, as a construct or framework, PCT tends to be outwards oriented (Pérez, 2018). That is, PCT practices can be and are introduced for the sake of disciplines other than computer science in itself (Weintrop et al., 2016).

To take advantage of the richness of these data, we add mathematical competencies as declared in the courses to the coding scheme, drawing directly from the curriculum: problem handling, modelling, reasoning and thinking, representation and symbolism, communication, and tools and aids. However, we only code a mathematical competency as being activated when mathematical concepts are involved. Niss and Højgaard (2019) emphasise that mathematical competencies refer to different sorts of mathematical situations, and thus this framework is inwards-oriented (Pérez, 2018).

Once all the tasks were coded, we applied the two dimensions of our the tasks in the following manner. We counted the number of tasks that represent only mathematical knowledge (at least one mathematical concept and no PCT concepts nor actions) and only PCT knowledge (at least one PCT concept or action with no mathematical concepts). These account for the juxtaposition of domains. In contrast, we count how many tasks include at least one mathematical concept and at least one PCT concept or action. These represent integration.

Among the integrated tasks counted in the first aggregation, we count the tasks where the integration is through PCT concepts, actions, or both. We analyse further into the data and identify prominent combinations of actions and concepts from both domains. For this, among the integrated tasks we count the share of which are combined with PCT concepts and actions. We conduct this aggregation according to mathematical subject-matter areas (reported in table 4) and competencies (reported in table 5) to account for the co-occurrence dimension.

Findings and discussion

Scholarly knowledge: PCT aids mathematical problem solving

We focus on the consensual aspects of PCT stemming from the first two questions of Kallia et al.'s (2021) literature-based Delphi study. Questions 1 and 2 concerned, respectively, PCT in mathematics education and the commonalities between PCT and mathematical thinking. Regarding the first dimension of analysis, we find the interplay to be a mixed case of integration and juxtaposition.

The case for an integration is grounded on the many consensual common aspects to both types of thinking (question 2) that characterise PCT in mathematics education (question 1): decomposition, pattern recognition, algorithmic thinking, modelling, abstraction, logical thinking, and structured problem solving. The *integration* implies that many characteristics of PCT are an organic part of mathematical activity. However, for question 1, decomposition, pattern recognition, algorithmic thinking and modelling are followed by the expression ”to solve a problem” (Kallia et al., 2021, p. 176). In that sense, PCT is a set of appropriate thinking processes that aid mathematical problem solving. Moreover, an aspect only raised in question 1 is that of ”being able to transfer the solution of a mathematical problem to other people or machines” (Kallia et al., 2021, p. 176). Therefore, PCT in mathematics is somewhat juxtaposed, in the sense of being a toolkit subordinated to mathematical problem solving as a goal, with the additional solution strategies are formulated in such a way that can be unambiguously communicated.

As for the second dimension, a few aspects derived from the questions hint subject-matter areas from mathematics. In particular, abstraction, generalisation, algorithmic thinking and pattern recognition can be linked to algebraic thinking (Bråting & Kilhamn, 2021). However, this is not exclusive to algebra. For example, seen as the selection of relevant elements of a problem, is a step of any modelling practice (Ejsing-Duun et al., 2021), mathematical, computational or otherwise. The recognition of visual patterns and generalisation are part of the development of geometrical abstraction (Burger & Shaughnessy, 1986), particularly in tasks aided by programming (Benton et al., 2017). Furthermore, abstraction and pattern recognition are essential data practices that relate to statistics (Weintrop et al., 2016). Overall, the commonalities between CT and mathematical sub-areas are not explicitly identified in Kallia et al.’s (2021) study.

Curriculum: a juxtaposition of PCT and mathematics

The experimental version of the mathematical curriculum positioned the new TC content as a fifth competence area in the mathematics curriculum (see table 1). This implies that the mathematical goals from the previous curriculum were not revised. Rather, new non-mathematical PCT elements were added in a juxtaposed manner to the existing mathematical components of the curriculum. This implies that PCT competencies and learning goals included in the mathematics curriculum described above are structurally disconnected from the existing mathematical competencies and learning goals. This implies that the new curriculum is to include PCT in mathematics by rather superficially coordinating it to the existing mathematical components of the curriculum.

In spite of the structural juxtaposition, it is worth examining the descriptions of competency areas from TC that were selected to become part of the pilot version of the mathematics curriculum. The competency areas of modelling and programming are described in generic terms without explicit relation to mathematics, nor to the existing mathematical competency areas in the curriculum. The curriculum goals for modelling state that students should have knowledge of how models can be used to describe the world and be able to construct and act upon models of the world and assess their domain (BUVM, 2019). Mathematical content is thus not explicitly mentioned. Similarly, the programming goals define that students should have knowledge about methods and stepwise development of programs and be able to modify and construct programs to solve a given task; no mentioning of mathematical knowledge nor skills. Moreover, despite the fact that the curriculum specifies that students should be able to both model and program concrete tasks in defined contexts, mathematical content is, however, neither mentioned as a context for the types of tasks to solve nor as a component of modifying or constructing programs.

The goals for data, algorithms and structuring and computer systems are, however, more explicitly related to mathematics. The goals for data, algorithms and structuring specify that students should acquire knowledge about patterNs in the structuring of data and algorithms, and that they should be able to recognise and use patterns in the structuring of data and algorithms in concrete problems. In the Danish mathematics curriculum, patterns are both part of algebra (number patterns) and geometry (in relation to placements and symmetry). In this sense, the data, algorithms, and structuring both include knowledge and skills that relate directly to mathematics. The curriculum does not, however, explicitly state these relations, which are up to teachers to infer.

Overall, there are great differences among the three PCT competency areas described above. As seen in the case of modelling and programming, it is not a given that the PCT competency areas in mathematics include mathematical knowledge and skills. As seen in computer systems, neither is it a given that it is made explicit how mathematical concepts are to be activated by PCT skills. This implies that an important step in integrating PCT and mathematics in the mathematics classroom is to connect PCT competencies with mathematical competencies as part of the internal didactic transposition. Thus, we consider, at the external didactic transposition, the relation PCT and mathematics as juxtaposed.

Teaching resources move towards integration

In the realm of PCT, the coding is relatively balanced. Seventeen percent of the tasks contain *modelling* concepts, 33 % include *programming* concepts, and 28 % make explicit concepts of *data*, *algorithms and* *structuring*. As for PCT action, the least present is to envisage (9 %), while the most frequently coded is to explain (31 %). These results do not suggest any strong preference or bias in the inclusion of PCT in the mathematics teaching resources.

The following results from the analysis help us characterise the teaching resources more globally:

1. Out of the 214 coded tasks, 11 are only mathematical, and 77 are only PCT. In contrast, a total of 115 integrate both domains. All in all, teaching resources characterise predominantly an integration (54 %) of mathematics and PCT, as opposed to the result of juxtapositions thereof (41 %).

2. As for the co-occurrence analysis, we summarise the results in tables 4 and 5. We remind the reader that the coding scheme is not exclusionary; concepts from more than one subject-matter area can be coded in the same task, as well as mathematical competencies and PCT actions. We have added, at the bottom of each of these tables, the total of coded tasks per column. These numbers can help contextualise reported frequencies therein.

Considering the totals in table 4, integrated tasks can be characterised by an underrepresentation of numbers and algebra, compared to a balance between geometry and statistics. The PCT subject-matter area of *modelling* tends to be the least integrated in all three mathematical

Table 4. *Integrated tasks with PCT concepts and actions by mathematical subject-matter areas*

	Numbers and algebra	Geometry and measuring	Statistics and probability
Modelling	6	11	11
Programming	6	17	19
DataAlgStruc	10	16	17
Follow	3	12	14
Figure out	5	11	14
Debug	1	3	7
Program	10	24	10
Explain	6	16	18
Envisage	4	8	3
Bridge	7	14	11
Total coded	25	56	51

areas. Though the general coding indicates *explaining* as the preferred PCT action, this is only reflected in statistics, while programming is the preferred action when integrating PCT with numbers and geometry.

The content of table 5 reflects the nature of the initial coding. The mathematical *problem-handling* competency has no presence and the mathematical *modelling*, and *representation and symbolism* competencies are underrepresented due to the absence of explicit mathematical concepts in the tasks. For this reason, many frequencies reported in table 5 are two small from which to draw robust quantitative claims.

Nevertheless, a few points can be highlighted. The tasks do not particularly exploit the relation between computer modelling and mathematical modelling. In relative terms, the few tasks integrating mathematical modelling do so with no preference towards computer modelling concepts.

PCT is integrated mostly with the mathematical *communication competency*. *Explaining* is, unsurprisingly, one of the most integrated PCT actions (18 tasks), though *programming* is the highest (20 tasks). To *follow* a procedure comes next (16 tasks).

The mathematical *tools and aids competency* comes in second place as the most integrated with PCT. This is somewhat counterintuitive, considering that TC in Denmark is a response to the irruption of digital

Table 5. *Integrated tasks with PCT concepts and actions by mathematical competencies*

	Problem handling	Modelling	Reasoning and thinking	Representation and symbolism	Communication	Tools and aids
Modelling	0	3	2	0	11	15
Programming	0	3	13	1	14	16
DataAlgStruc	0	5	17	1	28	4
Follow	0	3	9	0	16	8
Figure out	0	4	4	1	12	11
Debug	0	4	1	0	6	6
Program	0	6	6	0	20	20
Explain	0	3	15	1	18	11
Envisage	0	2	3	0	5	7
Bridge	0	3	2	1	10	14
Total coded	0	19	31	1	61	43

artefacts in everyday life (Tamborg, 2022). Contrary to the general coding, it is combined with more modelling concepts than data, structures and algorithms. Moreover, to *program* and to *bridge* are more often combined with this mathematical competency than the general coding that prefers *explaining*.

Concluding remarks

In this article, we aimed at understanding and characterising the inclusion of PCT into the mathematics curriculum and corresponding teaching resources in the external didactic transposition.

Our characterisation of this interplay in scholarly knowledge is based on Kallia et al.'s (2021) literature-based Delphi study. PCT is juxtaposed to mathematics in the sense of being a collection of thinking processes at the service of mathematical problem solving, with the particularity of being able to communicate and transfer solution strategies to other people or machines. To another extent, these domains are integrated, in that the practices that aid problem solving are common to PCT and mathematics. This integration, however, does not specify mathematical subject-matter areas. Furthermore, it means that the historical and epistemological overlaps between mathematics and computer science as disciplines (Gadanidis, 2017; Modeste, 2018) do not coincide with the more generic but subordinated connection between mathematics and PCT as teaching-learning subjects (Kallia et al., 2021; Weintrop et al., 2016). On this scholarly basis, we can now address our two research questions.

What is the relation between mathematics and PCT in the external didactical transposition when focusing on the newly developed curriculum to integrate TC and mathematics? PCT is part of the Danish national curriculum, as part of the new subject TC in the form of three subject-matter areas: *modelling; data, algorithms and structuring;* and *programming.* These areas have been added to the curriculum as part of a fifth competence area, after mathematical competencies, algebra and numbers, geometry and measuring, and statistics and probability. The descriptions of PCT components suggest some relation to mathematics, in particular, *data, algorithms and structuring*, given that computer science and mathematics share several aspects (see e.g. Modeste, 2016; Bråting & Kilhamn, 2021), and the associated skillset takes a point of departure in specific problems.

The inclusion results in a curriculum consisting of juxtaposed components from PCT and mathematics, indicating that new mathematical skills and knowledge are formed only to the extent that the TC competency areas include mathematics in themselves. They are, therefore, not formed by integrating new PCT aspects into existing mathematical competencies. This component of the external didactic transposition is here faithful to scholarly knowledge, to the extent of PCT and mathematics being juxtaposed and the integration relying on commonalities between them. This is illustrated by portraying modelling as a PCT competency area. However, the main difference lies in that Kallia et al.'s (2021) findings position mathematical problems at the core of this relation, while the pilot curriculum points to generic problems and makes no connection to the mathematical problem-handling competency (Niss & Højgaard, 2019). Moreover, the curriculum does not mention the transferability and reliability of solution strategies raised by scholars.

What is the relation between mathematics and PCT in the external transposition when focusing on the teaching resources developed to accompany the newly developed curriculum? The task analysis characterises teaching resources predominantly as an integration of PCT into mathematics, making this stage of the external didactic transposition rather conflicting.

Regarding subject-matter areas, this integration is biased against *numbers and algebra* in the mathematical realm, and slightly against *modelling* as a PCT area. In turn, algorithmic thinking, abstraction, generalisation, pattern recognition – associated to algebraic thinking – and modelling the are some of the common aspects between PCT and mathematics highlighted in Kallia et al. (2021).

Concerning the PCT actions, *explaining* a code, procedure, pattern or concept is the most integrated action, followed by programming, particularly when combined with the *communication*, and *tools and aids* competencies. These two are the most integrated mathematical competencies. These characteristics fit the particularity of PCT as an approach that allows strategies to be unambiguously communicated and transferred to other people or machines (Kallia et al., 2021).

One can spot some missed opportunities for this integration. For example, the mathematical *problem-handling* competency is not declared in any of the teaching materials. . The external didactic transposition revealed in this study places the responsibility of developing meaningful and coherent integrations on curriculum material developers and, in part, in concrete teaching on the shoulders of teachers at the level of the internal didactic transposition. According to the report on TC, Danish teachers mostly rely on the supporting resources for such a new type of subject (BUVM, 2021b). Therefore, it is likely that teachers do integrate PCT into mathematics (as opposed to juxtaposing it), but not subordinated to problem-handling. We consider this misalignment problematic since problem solving is considered the ultimate goal of mathematics education where computational thinking is embedded in scholarly knowledge (Pérez, 2018; Kallia et al., 2021). Our results show that the interconnections between computer and mathematical *modelling*, as well as the handling of *representations and symbolism* from both domains, are underexploited. However, these omissions may be interpreted as cautious steps, since the apparent synonymity of concepts such as modelling and function, and practices such as syntax and formalisms, can result in more of a challenge than a tool in teaching practice (Bråting & Kilhamn, 2021). At an international perspective, the English ScratchMaths project, for example, aimed at bridging the separated computing and mathematics syllabi, with no strong evidence of improving students' mathematics outcomes (Boylan et al., 2018). The Swedish Ifous project illustrated how difficult it is for teachers to use PCT as a tool for mathematics learning (Jahnke, 2020). Seen in this light, there is no evidence that a closer correspondence between scholarly knowledge and knowledge to be taught in fact will lead to improved mathematical learning on part of students. This points to a need for further research on to what extent identified potentials of PCT in mathematics education contexts can be exploited and under which circumstances. That is, a necessary follow-up is inquiring on the internal didactic transposition (Bosch & Gascón, 2006).

In spite that research on PCT in mathematics education has a long history, we are currently not at a stage where the research foundation to revise mathematics curricula to include are at hand. This calls for cautious and, most likely, iterative approaches to implementing PCT in the mathematical classroom, accompanied by ongoing research to study and assess the relation between approaches and learning outcome.

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Note

1 http://tekforsøget.dk/forlob

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