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Prototypes all the way Down

Prototyping in the teaching and development of technology comprehension

Simy Kaur Gahoonia, sgah@itu.dk, IT University of Copenhagen
Christopher Gad, chga@itu.dk, IT University of Copenhagen

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Abstract

This paper examines enactments of prototyping in a recent experimental effort to introduce 'Technology Comprehension' (TC) as a mandatory school subject in the Danish Public School. The overall concern of the programme was to educate young people to become not only users, but makers and analysts of the digital technological society. We adopt a social-theoretical view of prototyping that suggests it has moved well beyond design, and has become part of a broader cultural repertoire. We explore the capacity of prototyping as a site of social knowledge-production, illuminating prototypes as instruments of experimentation, epistemic negotiation, and civic participation. We analyse two prototypes: 1) an artefact that was the outcome of a pupil's work in a TC lesson; 2) an experimental lesson plan called 'App Design' put to use by a teacher in a series of 5th grade TC lessons. Attending to how prototyping is performed in the pupils', teachers', and subject matter experts' making, demoing, testing, and iterating on 'first type' tangible and material artefacts–prototypes. Prototyping in the trial programme can be understood as the rehearsal of chaotic conditions, in the teacher-pupil relation, and in the pupil-world relation. Prototyping can absorb the seeming impossibility of bridging 'theoretical' and 'practical' knowledges, and make new social and material agencies arise. The trial of TC seems in this light as much as an experiment in rendering social relations and knowledge-making, open-ended and experimental as it is an experiment in cultivating that exact attitude towards technology, but also towards societal affairs and knowledge-production.

Keywords

technology comprehension; prototyping; subject matter development; experimentation; school education

Introduction

This paper is an explorative and critical examination of a recent experiment to introduce 'technology comprehension' (TC) as a mandatory subject in the Danish public primary and lower secondary school (Folkeskolen, "the public school"), as a series of enactments and inflections of *prototyping*. We begin by discussing the context of the trial programme and how prototyping mattered. We then discuss the approach to prototyping, which we use to examine some of the social, technical, discursive, and material elements at stake in two prototyping enactments within the trial.

As we show, prototyping in the trial programme became more and other than what had originally been intended. Something more and other than a teaching form and technique aimed at enabling school children to get 'hands on' experience and become actively engaged in tackling the complexities of social forms of digitalization. It remains unclear how prototyping really mattered to the students subjected to these learning activities. Our argument focuses on how prototyping bound diverse activities together within the context of the trial programme as a whole. The trial programme became prototyping *all the way down*[1], we argue, by catering to the broadly accepted view that all kinds of activities—from dealing with technology, subject matter development or teaching practices—can, and perhaps should, be framed in terms of open-ended digital probing and tinkering.

Finally, we discuss how inflections of prototyping appeared in the trial evaluation and how this connected with the ultimate failure to convince politicians to introduce TC as a mandatory subject.

1 In reference to the epistemological problem of infinite regress.

Background and Empirical Methods

Over the last decade, Danish politicians, industry spokespersons, and experts have increasingly aligned in arguing that future citizen-subjects urgently need to develop their IT proficiencies to keep up with digitalisation. In the words of the Minister of Education (UVM 2018a), young people must be educated to become *not only users, but makers and analysts of the digital technological society.* But how to accomplish this is more contested. That was also the case when the Ministry of Education (hereafter 'the Ministry') launched a trial programme to inform political decision-making about future compulsory education in the area (Erhvervsministeriet 2018; UVM and STIL 2018a). From 2018-2021, the public school became the site of an ambitious large-scale experiment in developing TC as a completely new subject matter that would combine computing, design (see Gahoonia, 2023), and the humanities. This subject matter would familiarise schoolchildren with creative-constructive practices, i.e., digital design processes, 'making' and tinkering, problem-solving with digital technology, and with analysing digital artefacts in everyday life. According to the rationale of the trial programme, these practices were integral to formative schooling and personal development of children which are tasks of the public school.

The trial had three main components. In this paper we focus mostly on 'the school trials': the period when experimental teaching of TC occurred in volunteer schools[2]. The school trials took place in parallel with capacity-building efforts in the national teacher education programme, after an initial conceptualization of the subject matter proposal (UVM 2018b; UVM 2018d)

In preparing and conducting the school trials, the Ministry was aided by a consortium of subject experts and developers from research institutions. This consortium called itself 'Tekforsøget'[3]. The school trials focused on pedagogic-didactic teaching resources, which Tekforsøget called 'didactic prototypes.' Teachers would use these prototypes to plan and carry out their teaching. The trials ended in 2021 after three years of extensive subject matter development and teaching activities at 46 schools. The evaluation of the trials by Rambøll Management Consulting (2021) was largely inconclusive.

Here we draw on empirical material collected through ethnographic methods and desk research[4]. Additionally, we draw on observations from meetings (involving teachers and subject matter developers), participation in school research conferences about TC, and informational and inspirational material about the programme, the trials, and TC generally, distributed by Tekforsøget and the Ministry.

Prototyping in the Trial and Prototyping Cultures in STS

In the context of the trial, prototyping was regarded as a motor in pupil-facing teaching and the pedagogical development of TC. This was strongly, though not exclusively, inspired by Participatory Design (PD)[5]. Before developing our STS perspective on prototyping worlds and cultures, let us therefore first consider what prototyping means in PD.

In PD prototyping originally responded to a lack of user involvement in software development and to awareness of the fragility of user involvement processes. By the early 1980s, Floyd (1984) observed that prototyping denoted such a large variety of practices that any strict definition would be pointless. Floyd argued that prototyping

2 Though volunteering, the selected schools that took part in these trials received financial support from the Ministry to do so.

3 From the official website for the school trials at https://tekforsøget.dk

4 Including Gahoonia's observations between September-November, 2020 of TC classes and teacher preparation at a school located in the Capital Region of Denmark.

5 Arguably, prototyping as well as the set-up and many concrete technologies used in teaching (like Scratch, and micro:bits, and the curriculum frame for TC are also rooted in Silicon Valley ideology and an Anglo-Saxon 'literacy' tradition, which, in many ways, conflict both with the Danish 'dannelses'-tradition and with PD. In our interpretation, 'Tekforsøget' was, at least rhetorically, more grounded in the PD approach. This furthered its legitimacy as a genuinely Danish and democracticising practice (rather than an American import).

had multiplied for various reasons: because it is always embedded in broader systems development processes, because the functions and purposes of software are often ill-known in advance of development, and because software always remains 'unfinished' - 'in beta'. This is why the relation between the 'prototype' and the 'product' is much more complex when making software than in cases where prototyping designates a "first of type" in the manufacturing of a simple product. Thus, Floyd categorized prototypes according to purposes and the degree of openness in the development process: as explorative, experimental, or evolutionary. The common thread to these 'modes of prototyping' is that they all substitute "the [rational planning mode of] anticipation of a future system by a process of learning and practical experience" (15).

This understanding was crucial to the trial of TC. The trial adopted the notion that trying to tame the future with rational planning methods, e.g. requirements specifications, is futile. Instead, children must learn to cope with the uncontrollable nature of technology over time. This entailed continuous learning in practice, and involved the idea that future citizens should be able to contribute to the making of digital technologies that fundamentally shape their lives[6].

This understanding of prototyping has been partially accepted in STS. But it has also been expanded and transformed. In 2002, Lucy Suchman, Randall Trigg, and Jeanette Blomberg argued for adopting a more complex view of prototyping. They reported on a case study of a prototype deployed as

> "an exploratory technology designed to effect alignment between the multiple interests and working practices of technology research and development" (2002: 167).

6 Central to the early discussions of prototyping in PD was also the question of whether prototyping was mostly about enabling creative imagination and co-design or about excavating pre-existing assumptions, habits, or tacit knowledges (e.g. Mogensen 1992). Another central concern in the Scandinavian tradition has been a democratic politics. In early developments, PD was done in cooperate on with trade unions and was about involving workers in improving their work process, rather than turning them into subjects of automatization, surveillance and control (see e.g. Bjerkness et.al 1987).

In this case, the prototype remixed past and future assumptions, visions, and different social and material agencies, producing new socio-technical configurations. Suchman, Trigg, and Blomberg (2002: 176) state that

> "the prototype offers a perspicuous case of a performative artefact that works to align multiple, discontinuous social worlds. Like any technology, the prototype does not work on its own, but as part of a dynamic assemblage of interests, fantasies, and practical actions, out of which new socio-material arrangements arise."

In this view, prototyping affords making connections between existing worlds but is also about building 'open' future worlds (see also Maguire 2018). Prototyping is then not only a response to the 'openness' and volatility of technology development, but also its own performance of that openness.

Alberto Corsín Jiménez (2014) remarks on the emergence of a 'prototyping culture,' where visions, ideas and practices have moved well beyond design, and become part of a broader cultural repertoire for describing and engaging the world. To Corsín Jiménez (2014: 1), "prototyping has become an important currency of explanation and description (…), with an emphasis on the productive and processual aspects of experimentation." As such,

> "prototyping and experimentation have taken hold as both modes of knowledge-production and cultural and sociological styles of exchange and interaction" (ibid.)

In this view, prototyping even becomes generally descriptive of 'the social' as perpetually in the making.

Bringing these perspectives to the school trials, prototyping appears not only as a response to digitalization based on PD, but as performative of a digital world that works by enrolling pupils, teachers, and subject matter experts in making, demoing, and testing prototypes. These performances elicit

> "an epistemic culture built on collaboration, provisionality, recycling, experimentation and creativity, which seems as much oriented to the production of technological artefacts as it is to the social engineering of hope." (ibid.,382)

The Trial: Beyond Consumption via Prototyping Didactics

An important hope promoted by political actors, educators, expert observers, technologists etc., was that future citizens would evolve from 'passive consumers' to become 'actively' engaged with technology. Being active meant being creative, critical, and taking part in the construction of technologies. This notion of technology education is not unique to Denmark. A series of EU-sponsored mappings and reports (Bocconi et al. 2016; Bocconi et al. 2018; Bocconi et al. 2022) show that national school systems across the EU have lately been concerned with implementing subjects and curriculums, which teaches *more than* the use of technology. It is occasioned by a "growing understanding that digital competence goes beyond basic digital skills," (Bocconi et al. 2022: 5).

This is suggestive of what Macgilchrist et al. (2023) refer to as the postdigital condition, which is characterised by an increasing, if still modest, skepticism with respect to the capacity of technology to solve all problems. The emergence of phenomena like 'fake news,' cyberbullying, 'digital exclusion,' and commercial data-driven operations has produced a general awareness of the negative technical influences on democracy, well-being, and resource distribution (Schou and Hjelholt 2018; Maguire and Winthereik 2019; Carreras and Finken 2022). And, also, awareness of inadequacies in how technology is developed.

There are no self-evident solutions to all these problems. However, as 'the extended arm of the Danish welfare state' (Coninck-Smith et al. 2015: 383), the public school was in a position to educate young citizens about the issues, and hopefully making the future more democratic. This furthermore aligned with the concurrent government strategy to support "digital growth" (Regeringen and Erhvervsministeriet 2018) through formal education.

Throughout the trial, 'Bildung' and the priority of education formative of the subject as a social being was central to the debate. In response to the key question of what students should 'become' via TC (and what they therefore would have to know), experts appointed by the Minister of Education drafted a proposal consisting of Common Objectives (learning outcomes), a description of subject matters, and a teaching guide. This proposal was made public in December 2018. The overarching goal of TC was that: "The pupils should develop academic competencies and acquire skills and knowledge so that they can participate, constructively and critically, in the development of digital artefacts and understand their significance" (UVM 2018f: 3).

The expert group described four equally important 'competency areas' of TC: 1) "Computational Thinking" develops the ability of the pupil to translate a complex problem into something computable; 2) "Technological Knowledge and Skills" includes learning about computer systems and (programming) languages; 3) "Digital Design and Design Processes" aims to develop the ability to plan and execute a design process; and in 4) "Digital Empowerment", pupils explore digital artefacts: their possibilities, consequences, and impacts (UVM 2018e). While TC was not conceptualised exclusively as a design discipline, the proposal consistently emphasized the educational and formative value of creative-constructive design practice and rehearsing prototyping with pupils, stating, for example, that:

> "(...) it is central that pupils learn to construct with digital technology (program, develop prototypes or use fabrication technologies) and thereby get the opportunity to create new and rethink already existing digital artefacts" (UVM 2018g: 10).

Furthermore,

> "digital construction (including programming and prototype development) is central for this subject, and there will be thorough and focused work with this element - beginning from early schooling." (15)

In the trial, the notion of didactics[7] was strongly influenced by PD (Iversen, Dindler, and Smith 2019; Wagner, Iversen, and Caspersen 2020), where it was sutured with the civic and empowerment ideals of Danish schooling. Thus, the main architects of TC explain that

> "[in] a Danish educational context, the philosophy in participatory design can be viewed as a driving force for ensuring that the students don't just learn programming skills in school, but also become involved to such a degree that they can begin to cognise and create with the technology." (Wagner, Iversen, and Caspersen 2020: 10)

Furthermore, PD and empowerment were reworked into "Computational Empowerment;" a kind of companion concept to 'understanding of technology' as suggested by TC. Specifically, Computational Empowerment was defined as the ability of children to co-create the future that emerges through the construction of technologies (Iversen, Smith, and Dindler 2018).

Thus, sampled from continental European educational philosophies, research and theory on Scandinavian PD and the Danish tradition of informatics, prototyping became a central and normative concept, visibly on display in the trial, and imagined as crucial for cultivating postdigital citizenship. Prototyping was turned into a significant classroom activity in which pupils would construct technology, but it also became significant in terms of the organisation and conduct of pedagogical development work centering on TC didactics, where "the experimental and open-ended qualities of prototyping have become a surrogate for new cultural experiences and processes of democratisation" (Corsín Jiménez 2014: 382). Having discussed this framing of the trial, and its inspirations, we now turn to look more concretely at how prototyping unfolded.

7 Didactics is a "language in which a common framework and set of referents [govern] discussion of educational theory, the practice of teaching, schooling, curriculum making and lesson design, teacher education, school administration, textbook production, the sites of exchange between teachers, teacher associations and in-service professional development, as well as issues concerning individual school subjects, academic disciplines, and forms of knowledge" (Retz 2022: 415).

Prototype 1: A super animal

The first prototyping enactment we explore involves a 6th grade lesson, which takes place in the school's designated TC classroom. Our focus is one pupil's digital artefact and the conditions under which it was constructed and presented to the teacher during the lesson.

The lesson—in making 'super animals'—introduced rudimentary, imaginative, and playful coding exercises for children aged 9-13. The center was a small kit of open source, simple architecture hardware: the 'micro:bit'.

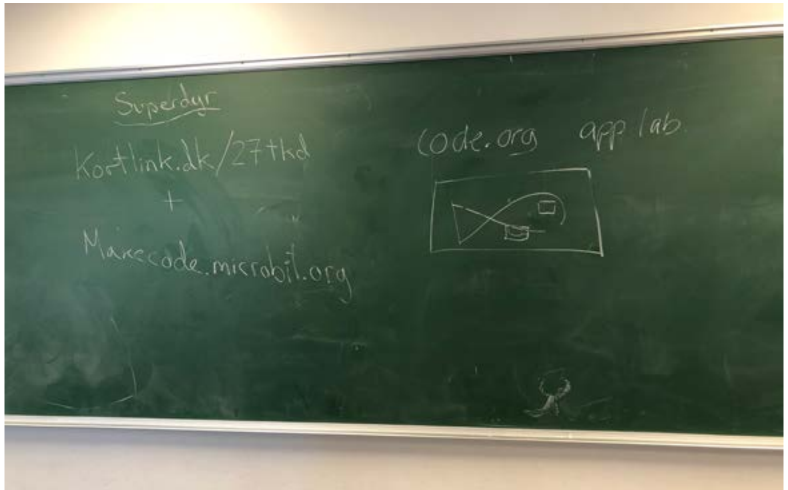

Figure 1. The blackboard with hyperlinks and writing in chalk. Photo by Gahoonia.

The super animals exercise was based on a design process model for TC developed at Aarhus University (see Hjorth et al. 2015), where it had been adapted from similar process models in professional engineering, design, and project management. The design process model of TC addressed various phases of a design process. As for super animals, its creative-constructive phases of design both correspond to and depart significantly from practices of problem-based learning and project work congruent with e.g. the 21st Century Skills paradigm and various new media literacies that map onto digital competence (see Ilomäki et al. 2016).

Drawing on these design approaches, it was a central point to make the subject practical. In other words, it should not be a matter of thinking, of cognition, and of 'talking about', but of crafting and getting hands-on experience with the stuff of digital technologies, here in the form of chip-like processors that transform human input into code. The super animal exercise was about materialising, with a mixture of analog, digital, and computational supplies, an animal with fantastical abilities. Under the title 'coding a better world', this exercise focused

on how animals might adapt to environmental change. Within that framing, pupils ideated and constructed partially digital artefacts in an iterative fashion.

The lesson offers a glimpse into the construction phase of the design process, as conducted by the pupil and supported by the teacher. The role of the teacher was to facilitate the iterative processes and *being in* these with the pupils. At the beginning of the lesson, the teacher gave a brief introduction, recapping previous key topics and aims for the day. A shortened URL was written on the blackboard, directing the pupils to the online material where the rest of the instructions, hyperlinks, and audiovisual resources were located.

The pupils then began working with analog and digital materials. The analog involved using cardboard or paper as the base structure for the super animal. Next this structure was 'fused' with small micro:bit computers, which had to be programmed first. Programming involved translating the imagined visual effect of an animal that changed or adapted into language understandable by the computer. The tool was Scratch, a visual programming language and environment, that presents code as blocks of different colours and shapes, which can be dragged and dropped to create syntax on the screen.

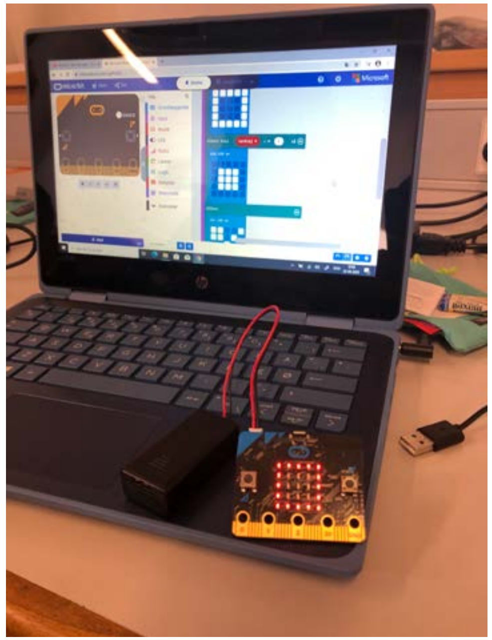

Figure 2. A micro:bit rests on a Chromebook. Photo by Gahoonia.

The pupils scattered into groups or worked individually, occupying the desks, floor, and spilling out into the hallway. The teacher facilitated the process, seeking to support pupil creativity and experimentation. For example, when noticing that there were not enough scissors and markers, pupils told the teacher, who enthusiastically leapt out of the classroom to fetch more supplies. The other teacher walked and sat among the pupils, supervising and engaging in conversations about their process.

One pupil constructed a working prototype of his super animal, which was composed of a sheet of white A4 paper where he traced a dragon-like figure with green marker (see fig. 3). When presenting to the teacher he did an informal 'demo' of this prototype. The fantastical abilities of the paper-based dragon was suggested by computational micro:bit hardware elements: Three micro:bit diode boards peeked out from cut-outs in the paper and lit up when he shook them. The dragon had dynamic scales, which could be seen when the micro:bit in its body was shaken. Shaking the 'tail micro:bit' let loose missiles. The eye was also a micro:bit that blinked when shook.

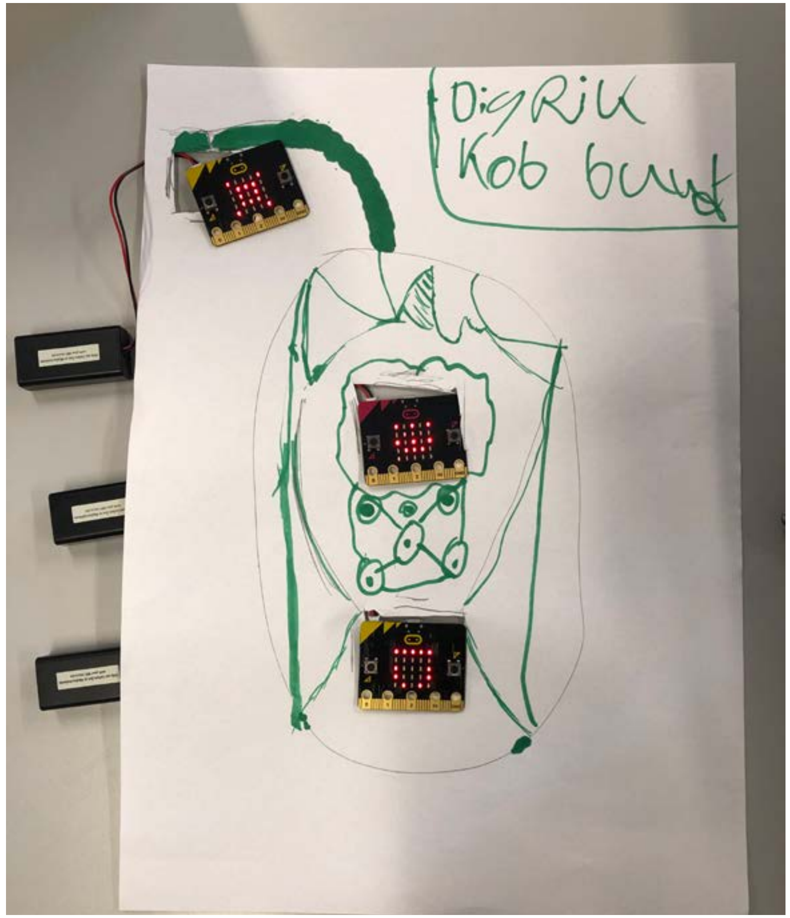

Figure 3. The pupil's prototype of a super animal. Photo by Gahoonia.

While demoing the prototype, one of the micro:bits remained 'stuck' on a static pattern of diodes. Neither the pupil nor the teacher seemed to know why. The teacher waved the failure aside and stressed that it was a fine piece of work regardless. She then asked how the pupil thought the creature could be further improved. Tongue-in-cheek he responded that there was nothing to improve as it was already perfect. The teacher laughed this off and began to inquire whether it had been fun to work independently on making this artefact. The pupil agreed.

This exemplifies how creative-constructive work and learning in TC is focused on the process of construction, and in this case more so than on the product or on reflections. This focus is promoted across the TC pedagogical experience, research, and literature. When demoed (?), the super animal elicited communication and feedback between the teacher, the pupil -- also including Gahoonia as participant-observer. The prototype is somewhat faulty. According to the teacher, it is an accomplished piece of work with room for improvement, while according to the pupil it should be left complete in incompleteness. These incongruent views coexist within a prototyping culture. They are indeed congruent with the learning outcomes of TC, since mobilising prototyping as a pedagogic-didactic principle allows for the negotiation of epistemic closure and opening. Thus, prototyping can be a currency of explanation and description and a style of social exchange.

As a performative artefact, the super animal prototype brings into view both social and material agencies of technology construction. Corsín Jiménez (2014: 1) suggested that "prototyping as something that happens to social relationships when one approaches the craft and agency of objects in particular ways." In this prototyping activity, the super animal variably performs 'the pupil', 'the teacher' and their relation in the teaching and learning of TC. It performs 'the teacher' as facilitator of an open-ended, experimental, error-prone, creative, and iterative–yet bounded–learning environment, and as someone who is less concerned with demonstrating authority on the subject matter. Simultaneously, the prototype performs 'the pupil' as playful and 'daring to fail' (*fejlmodig*). Thus, it inscribes and tests one of the significant reconfigurations of TC: shaking up the relations of 'pupil' and 'teacher' by placing them in an iterative process where closures and openings are negotiated. This relation is rehearsed, but so too are the complex, and often outright chaotic teaching conditions, which the pedagogical literature asks TC teachers to embrace (see Beksgaard et al. 2021), and which pupils need guidance through in order to feel safe 'failing' and navigating the supposedly inevitable failures embedded in this learning practice.

The micro:bit that failed during the demo shows how an expected lack of mastery of the creative-constructive process aligns with existing pedagogic, didactic, social, and organisational challenges of "the classroom as experimentarium for new technologies" (Riis 2012: 87). By allowing for incomplete or ambiguous relations of failure and success, prototyping absorbs the conditions of complexity that teachers see as the effects of technology on social and material processes of education. Said differently, prototyping offers a handle on a tension between the need to materialise technology and the idea that technology disrupts expectations. This can be understood as an embodied rehearsal, for both teachers and pupils, of future living with digital technologies as complex epistemic objects.

All in all, this case shows prototyping as a rehearsal of chaotic conditions, both in the teacher-pupil relation and in the pupil-world relation, an outsized part of which is precisely assumed to not be teachable 'in theory'. As one teacher remarked to Gahoonia, theoretical learning about these issues would be like 'dry swimming'.

In addition to this, the effects of prototyping proliferating in the trial can be elucidated through a contrasting example of prototyping enactment, which we turn to now.

Prototype 2: A Didactic Prototype

A consultant from Tekforsøget said that it was a deliberate choice to speak of "didactic prototypes," because it suggested that 'the grown-ups were taking some of their own medicine.' By this they meant that teachers would also be doing and learning about prototyping while teaching students how to do it. The second prototyping activity we examine is the collaboration between Tekforsøget and a teacher on the TC teaching team, which centered around the format of this didactic prototype. The prototype, App Design, was used for teaching, and the teacher gave feedback to a Tekforsøget developer over the course of the term.

The teachers had no formal training in how to teach TC to their pupils, given the novelty of the subject and the proposed didactics. In general, teacher education at university colleges does not include comprehensive subject-specific training unless the corresponding subject already exists in the school system. This created an obvious paradox in the introduction of TC. The situation was consistently problematised and remedies were also sought in innovative development practice. To this line of thinking, pedagogic exploration of TC was a matter of establishing subject-specific didactics that would address the bottleneck. Politically, the trial at large was framed as a test and knowledge-gathering effort, since there was no existing cohort of TC teachers. In this sense, TC was not a pre-implementation project but an experiment in pedagogy as well as (inter-) organisational practices.

In August 2018, Tekforsøget was contracted to lead the pedagogical development work (UVM 2018c). Part of their task was to create and prepare teaching materials and to organise the development work with municipalities that had applied to be part of the school trial (UVM and STIL 2018b). Most of the work to develop didactic prototypes was carried out from August to December of 2018. The school parties were then invited to 'co-create' (Tekforsøget 2018) TC with Tekforsøget over a three-year trial period. At a kick-off meeting for these trials, Tekforsøget presented this prototype format as "the first didactic and material starting point for the pedagogical personnel's work of trying out the new subject matter." According to Tekforsøget, the purpose of organising the trial around prototypes was to provide direction and 'scaffold' the testing, while also offering flexibility, and enable feedback and iteration.

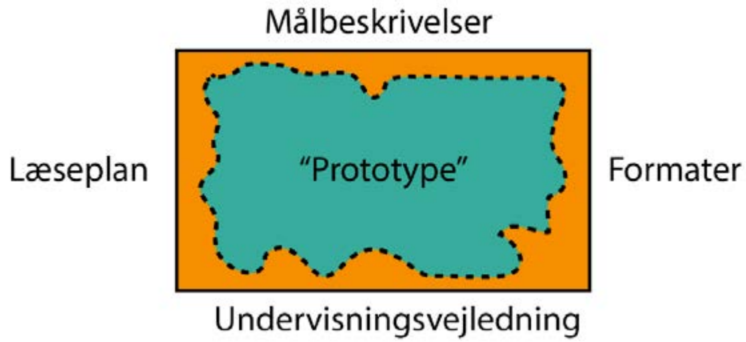

Figure 4. The model embedded on Tekforsøget's subpage on 'didactic principles' (Tekforsøget n.d.). From the top and clockwise: goal description, formats, teaching, and curriculum. Photo by Gahoonia

On their website, Tekforsøget described the didactic Prototypes as 'inspirational,' and illustrated their relation to other key steering documents such as the subject matter proposal's texts (curriculum, learning goals, and teaching guide). Furthermore, Tekforsøget stressed the importance of teachers trying out the didactic prototypes in TC teaching.

The didactic prototype 'App Design' aimed at the 5th grade. The prototype had been developed by subject matters developers–a group of teacher education researchers and pedagogical consultants–under Tekforsøget. The prototype consisted of 14-page long document based on similar template to other didactic prototypes, e.g. an orange front page with Tekforsøget's logo, consortium attributions, a table of contents, and a course description. The .pdf document was hosted and downloadable on Tekforsøget's website in a so-called 'the prototype bank,' a subpage that listed over a hundred such prototypes, audiovisual resources, and hyperlinks to relevant materials on the web.

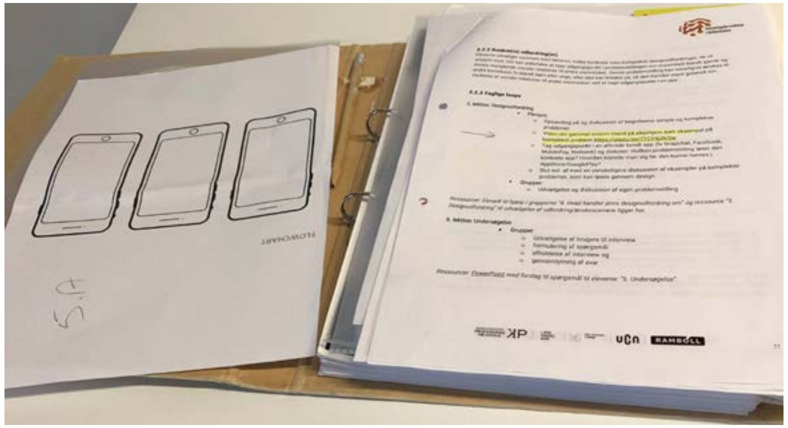

Figure 5. Open binder with a page of the prototype, with highlighted passages and notes. Photo by Gahoonia.

When planning app design lessons, the teacher had printed the prototype and put the pages into a binder, which he carried with him to the lessons. He had highlighted passages and made notes that prepared for and reflected on teaching of the prototype. The lessons observed by Gahoonia focused on the construction phase of the design process model. The pupils mostly did groupwork with paper-based app prototypes, usually after a brief introduction or recap of last week's activities. Occasionally, the teacher interrupted the work for a short discussion by the blackboard. An example was a discussion of visual aesthetics, typography and iconography in mobile app interfaces that sought to engage the pupils' understanding of the process and their own choices. According to the didactic prototype, the pupils were to make their apps in the programming environment AppLab after progressing with the construction of mockups and an initial round of demo and feedback. This was too difficult to do in accordance with the suggestions of the didactic prototype. For example, the teacher allowed the pupils to use PowerPoint to present their Apps since using AppLab programming was too complex and demanding. This illustrates challenges with reconciling the practical guidelines, the complexity of actually teaching the content, and the technological infrastructure and skills available. To solve the problems, the teacher made choices informed by his professional knowledge. Afterwards, he shared these observations with Gahoonia, the rest of the teaching staff, and in recurring meetings with Tekforsøget.

Figure 6. The teacher has lined up the pupils' poster prototypes to take a picture and share with the Subject Matter Developer. Photo by Gahoonia.

Tekforsøget had a learning consultant with subject matter expertise linked to the school—a subject matter developer. She would visit the school on occasion to discuss teaching methods, subject-specific didactics, exchange theoretical and practical knowledge, or listen to teacher experiences and collect general feedback. Feedback was also delivered virtually and asynchronously. In between these meetings, the 5th grade teacher would continue planning and teaching. Once after the pupils had finished their paper prototypes (posters), the teacher stayed in the classroom after the lesson ended and the pupils had left. He intended to take pictures of the posters and share them with the subject matter developer. Lining the posters up on a table and snapping photos of them, he commented that the developer would probably enjoy seeing the great work.

With these observations in mind, we wish to first bring attention to the role played by understandings of 'the theoretical' and 'the practical' in experiments and reflections among teachers, Tekforsøget, and subject matter developers. Tekforsøget had invited schools and teachers to co-create subject-specific didactics for TC, however, a shared understanding of 'the theoretical' and 'the practical', their differences, and their mutual constitution in the public school seems to be missing.

Among public school actors, awareness that the lines between the 'theoretical' or 'conceptual' and 'practical' can be blurry seems to be common. Reflecting on the TC trial at large, for example, one teacher remarked that the subject matter proposal was very dense, an example of 'deskwork', informed by abstract theory. Subject matter experts who may contribute to such deskwork as consultants readily agree that this can be a problem. This is why they encourage collaborations with teaching practitioners who can skillfully incorporate "the practical" in developing TC. Central to our argument is that naming this division (theoretical/practical) is a productive act, which creates a knowledge gap that prototyping can then be used to overcome.

As it inscribes pedagogical theory, research, and knowledge into a theoretical artefact that prefigures and models TC teaching, the didactic prototype performs this division. TC is stabilised in the didactic prototype, affecting alignment between distinct but also entangled and mutually constitutive social worlds of knowledge practice: 1) the ongoing quotidian teaching practice, materialized and localized in the lessons taking place in classrooms, the school term, and the amount of hours available to the teacher for a given task; and 2) the abstract deskwork and theoretical practice of advising, doing, and presenting pedagogical research, and consulting, which is much more distributed spatially, and temporally delineated by the 3-year school trial phase, and, more broadly, by cycles of policy and government.

The prototype is an artefact of ongoing pedagogical development work. It assembles pedagogical-didactic research, practical knowledge, steering documents, subject matter developers, and the curriculum. One way this is made significant to the organization task of developing and testing TC as an experimental subject is through the model shown in figure four, which Tekforsøget used to explain the role of the prototype. The dotted lines around the the didactic prototype indicates it is a deliberately ill-structured object, not unlike a boundary object (Star 1989; Star and Griesemer 1989). This facilitates "the productive and processual aspects of experimentation" (Corsin Jiménez 2014: 1) between epistemic cultures and supports the introduction of complexity (via new material and social technologies, roles and relationships etc.) into disciplinary canon. In the trial, the didactic prototypes constituted the tangible and material first instances of this emerging but still diffuse subject matter --purposefully and productively unfinished to make the teachers' participation seem meaningful and worthwhile.

Some of the feedback made it back into the development process. The prototyping arranged by Tekforsøget, for example, yielded new iterations of the didactic prototypes that were tested in schools at later stages of the trial. However, despite this fruitful outcome and a personal interest in the subject matter, the experience of the 5th grade teacher was ambiguous and complicated. Taking part in the trial and trying out didactic prototypes was, as he put it, like building a boat while at sea. Not unlike the idea of 'dry swimming' mentioned above, this image suggests that are limits to how many different social worlds and material agencies prototyping can absorb and transform.

Conclusion: The Afterlife of the Trial

The spread of a prototyping culture in the school is implicated with discussions about the role of public schooling and statutory education in general. As curriculum scholar Thomas Popkewitz (2012) remarks, education routinely mobilises the future to organise the present. In particular, prototyping culture involves the idea that a sense of experimentation specific to systems development and design is vital for civic participation in a digital democratic society. As culture-bearing institution, attended by ca. 86 % of all children ages 6-15, the public school holds potential to amplify, 'give scale' or 'reality' to certain idealized ways of understanding human-technology relations in a digital society.

For better or worse, the trial of TC consistently prioritised process over product. We see this in both prototyping enactments discussed above. In the first case, the emphasis was on attuning to the process (which is iterative and open-ended), human agency (critiquing and making design choices), and materiality (code, micro:bits, batteries) assembled in technology. But it was not on making good or viable technologies. In that sense, the product has a function, which is not technical but epistemic. By framing and absorbing uncertainty and failure, the function is to facilitate reflection on the digital construction process.

The second case presented us with a trial that was determinedly not an implementation project. The aim was to "test different models for strengthening 'technology-understanding" as a mandatory part public school-teaching." (UVM 2018d: 1) As theoretical-conceptual artefacts with practical use in local schools and beyond, the didactic prototypes exhibit open-ended testing and exploration as legitimate and desirable markers of knowledge. This is further amplified by the evaluative efforts that followed the conclusion of the trial phase in schools.

In 2021, Rambøll Management Consulting, a partner in the Tekforsøget consortium, (subcontracted to carry out evaluations) published their assessment of the school trials (UVM 2021). Based on interviews and questionnaires with involved teachers, the report notes that some content was too hard for the youngest pupils and that the subject required engaged teachers and supervision. But the major source of concern has to do with methodological issues. The SARS-CoV-2 pandemic, the large variability of how the subject was taught at the 46 different schools, and mid-way changes to the evaluation process itself - namely a cancellation of the use of "taskforce and comparison groups"- are mentioned as reasons for such cautiousness (18).

In line with 'classical' actor-network theory, Jensen and Lauritsen (2005) observed that policies and policy reports are often open-ended because they must align with many interests. As an underspecified concept, prototyping certainly supported the conduct of the school trials for similar reasons. But the evaluation also remains open-ended because the effects of the trial cannot be separated from the social life of school children (see also Marres and Stark 2020):

> "Concretely, the quantitative investigation does not make it possible to conclude if the pupils got better at TC because of the trial, as it is not possible to isolate the effects of the trial from the expected natural development of children as they grow older and increasingly get access to and experience technology" (UVM 2021: 18).

The report nevertheless indicates that the trials and the evaluation could have deployed other, and possibly better, methods. Thus, both the trial activities and the evaluation also appear prototypical. Everything is mixed up with something else and everything-- from teaching to the evaluation itself-- must be seen as an unfinished but improvable form. It is prototypes all the way down.

Almost half a year after the evaluation, the Ministry still had not announced anything about TC's future in the public school. When prompted by media, policy makers offered ambiguous answers (Marthinsen 2022) and acknowledged that the future was uncertain (Wittorf 2022). But although this specific trial may not have much of a future, the implications of scaling up a prototyping culture by seeding it in the public school deserves careful attention.

The fact that the trial ended with a 'non-conclusion' and non-decision was controversial to many of those involved. Arguably, however, the trial itself was much more controversial. After all, the last time a new school subject was made mandatory in Denmark was more than 25 years ago. In this context, the demo-ing, failures, scaffolding, and feedback which prototyping allows–as shown in the prototyping activities that the super animal and the didactic prototype are assembled and performed in–seems at once hopeful and disappointing.

For the time being, TC remains a prototype—'underdeveloped' in a way. The subject matter has been defined sufficiently well for testing, but it has not been realized as a new school subject. Thus, TC lives on as didactic prototypes capable of sometimes traveling to particular schools, and to arenas like pedagogic research, education consultancy, or extracurricular coding clubs. To a significant degree, TC has also become an embodied experience and tacit knowledge among the teachers, subject matter developers, and pupils that took part in the trial. Like many prototypes of PD, TC was shelved – until the government announced that TC would not become a mandatory topic but an elective. The trial of TC thus continues, beyond the confines of the ministerial programme, as an experiment in rendering social relations and knowledge-making open-ended and experimental, and cultivating that exact attitude towards technology, but also towards societal affairs and knowledge-production in general.

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Author bios

Simy Kaur Gahoonia, PhD, is Research Assistant in the Technologies in Practice group at the IT University of Copenhagen. Her current research interests include postdigital schooling, the knowledge practices of education, and experimental conduct in social change.

Christopher Gad, Ph.D., is Associate Professor in Technologies in Practice at the IT University of Copenhagen. He is chair of the Danish Association for Science and Technology Studies. His current research interests include the influence of digitalisation and computer science on how we think about trust in society.