"Look at our smart shoe" - A scalable online concept for introducing design as part of computational thinking in grades 1-6

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Published in:
Proceedings of IDC 2023 - 22nd Annual ACM Interaction Design and Children Conference

DOI:
10.1145/3585088.3589377

Published: 19/06/2023

Document Version
Final published version

"Look at Our Smart Shoe" - a Scalable Online Concept for Introducing Design as Part of Computational Thinking in Grades 1-6

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ABSTRACT

While programming is a process covering many stages, many of the tasks K-12 students meet at school are small with little need for, e.g., analysis or design. These earlier phases are, however, important to let children meet open-ended problems, brainstorm solutions and ideate their own creative designs. In this paper we present a model for an online, scalable and scaffolded design workshop for covering such aspects at K-12 level. Through a case study with 1200 students and 60 teachers on IoT and smart things, we describe the workshop and the resulting designs. While the students managed to design their own artifacts, more time had been needed for covering ethical aspects related to technology design. The results suggest creating separate workshops for different grade levels, and also for design and ethical aspects respectively. Moreover, additional resources could support teachers in continuing the discussion with the students after the workshop.

CCS CONCEPTS

• **Social and professional topics → K-12 education**; **Computational thinking**; • **Human-centered computing → Participatory design**.

KEYWORDS

Programming, Computational thinking, K-12 education, Online workshop, Design, Case study

ACM Reference Format:
Linda Mannila and Mia Skog. 2023. "Look at Our Smart Shoe" - a Scalable Online Concept for Introducing Design as Part of Computational Thinking in Grades 1-6. In *Interaction Design and Children (IDC '23), June 19–23, 2023, Chicago, IL, USA.* ACM, New York, NY, USA, 11 pages. https://doi.org/10.1145/3585088.3589377

1 INTRODUCTION

In the last decade, there was an intense debate on the need for integrating programming and computational thinking (PCT) into K-12 education. For instance, in 2013, Informatics Europe and ACM Europe published a report [20] emphasizing the importance of helping all children 1) develop the skills to use the technology, 2) understand the science behind the technology as well as 3) get insight in the possibilities and challenges it brings. Similar calls were made globally, resulting in revised core curricula in many countries [1, 3, 17]. While some countries have introduced a completely new subject, others, such as Finland, have integrated the new content into existing subjects [3].

Programming is a process, consisting of several phases, such as problem analysis, brainstorming, design, implementation, debugging and refinement, which are iterated once, or more commonly, several times. When teaching programming at lower levels of education, the problems to solve or ideas to implement are commonly so small that there is no need to focus on the early stages of the process. For instance, the task may have only one or a limited number of possible solutions, rendering the phases of brainstorming and comparing different ideas obsolete. Rather, students often go straight for the coding phase, possibly first designing the solution on paper using a flow chart. Moreover, many students primarily meet programming in applications that provide closed ended tasks, leaving even less space for anything but coding.

Research indicates that there are many benefits to this approach. Nevertheless, the earlier phases of the process are also important in order to give children opportunities to consider open-ended problems, brainstorm possible solutions and develop their own creative designs [8, 39, 44, 49]. In addition, there is a debate on moving from computational thinking to computational empowerment (e.g., [23]), highlighting the need for children to understand and make informed decisions about technology's role in society and their lives. These areas are also part of curricular objectives.

Introducing PCT in K-12 education has, however, proven challenging. Several of the challenges of introducing new content in education are related to the conditions and opportunities teachers feel they have or do not have [52]. In the case of PCT, most teachers lack previous experience, sufficient training and time [35, 45, 52]. The curriculum changes have thus highlighted a large-scale need for professional development and redesign of current syllabi, as well as good examples and resources for teaching and learning. It is reasonable to assume that adding new dimensions to what needs to be taught about PCT would give rise to similar challenges.

In this paper, we present a model for an online workshop that introduces students and their teachers to the early phases of the programming process. The concept is interactive, participatory and collaborative, including four design sprints, letting students brainstorm and design their own artifacts on paper. The workshop has so far been arranged twice on the topic "IoT and smart things", having reached roughly 1200 students aged 7-12 and their teachers geographically dispersed throughout Finland. In addition to describing

IDC '23, June 19–23, 2023, Chicago, IL, USA

ACM ISBN 979-8-4007-0131-3/23/06.
https://doi.org/10.1145/3585088.3589377

the model, we present the results of an analysis of the students' designs, providing insight into their ideas of a smart everyday thing. Thereby, we aim at addressing the following exploratory research questions:

- R1: How can design and societal aspects of PCT be introduced at K-12 level in a scalable manner?
- R2: What features and characteristics can be found in students' designs of smart things?

We begin by presenting the background and settings for our study, after which we present and discuss the results.

2 BACKGROUND

2.1 Computational thinking, empowerment and design

The rationale for introducing programming in K-12 curricula is not to train future programmers. Rather, the goal is to help children develop their computational thinking (CT) skills, that is, a fundamental set of concepts, approaches and attitudes for solving problems with the help of computers [53, 54]. Many frameworks and definitions (e.g., [2, 4, 6, 21, 47]) have been developed aiming at describing what CT entails in practice.

In addition, there has been a debate on the focus of CT education (e.g., [7]), which has also been related to literacy (e.g. [24]). In addition, Kafai et al. [26] argue for three different types of CT: cognitive, situated and critical. They argue that K-12 education mainly focuses on the first framing of CT, where emphasis is placed on practical skills and computing concepts thought to be useful for the students' careers. Situated CT, on the other hand, points out the value of students engaging in design as well as discussing and sharing their artifacts with others. In this framing, students' practical skills and their understanding of CT concepts are still important, but the main goal is to highlight how students can use these competences to express their own interests and identities. This focus may also appeal to children, as the freedom to imagine and invent is what many young people appreciate the most about technology education [33]. Finally, according to the critical framing, CT is considered a vehicle for discussing and engaging in societal aspects of technology, such as challenges related to ethics, sustainability and politics. The authors highlight that all of these framings should be present in K-12 education.

These framings are closely related to the discussion around PCT at K-12 level in terms of empowerment [44]. One rationale for introducing PCT to children and youth is to support them in becoming active producers rather than mere passive consumers, as well as learning how to benefit from the opportunities and limit the negative consequences technology brings [34]. At the same time focus has increasingly turned towards design by children as opposed to the traditionally more common design with children [19, 50]. Letting children become more active participants, make their voices heard and have an influence in the design process can help them feel more empowered [22, 29]. Children can participate in a design process in different roles, as users, testers, informants, and design partners [12], and each role offers different degrees of empowerment. Involving the end user in the design also democratizes the process and tends to result in more relevant and ethically sound solutions [42]. Moreover, according to the UN Convention on the Rights of the Child, children have the right to be heard and express their ideas on matters that affect them [50].

When including children as active participants in the design process, the methods used need to take into account the age and number of the participants, the level of involvement and the settings and design context [48]. Common design approaches, such as user-centred design, learner-centred design and participatory design, have all been used in co-design activities with children, offering different degrees of participation [48]. Participatory design, or co-design, is grounded in the idea that users are most qualified for making decisions on their needs, and such processes can hence both empower the user in shaping new technology and result in viable designs [36]. The tools needed can be low-tech, such as paper, crayons and clay [11, 41], making prototyping inexpensive. Moreover, using familiar art supplies reduces the need to explicitly teach basic prototyping, as such tools are both familiar and natural to most children [11].

2.2 Smart things as the design context

The Internet of Things (IoT) gives concrete examples of how digital technology is being embedded in our everyday lives and physical surroundings. Many of children's everyday activities center around "things", which were traditionally physical toys and books, but are now increasingly complemented or augmented with a digital – or smart – dimension. A "smart thing" can be seen as a computationally enhanced version of an everyday thing, able to communicate with the world through input and output devices [15, 31]. As these technologies are complex and embedded, they can be difficult to grasp and understand for non-experts. Still, letting children discuss and design smart things, without the need to technically implement them can be empowering and help them meet CT in a situated and critical framing [27].

Consequently, despite the complexity of the topic, IoT and smart things have been used as the design context in workshops aimed at children (e.g., [10, 16, 43]). Commonly, the design of a smart thing is depicted in three main phases [40]: 1) exploration and familiarization, 2) ideation and conceptualization and 3) programming and prototyping. Hence, design workshops with children should start by exploring what smart things are and how they are made [15]. In order to be authentic and genuine, the workshop should then continue with the ideation of smart things, letting children imagine and conceptualize their own smart solutions [43]. Depending on the background and previous experience of the children, as well as the goal of the workshop, the third phase, programming and prototyping, need not be included. Rather, the end product can be the students' designs made using a given design toolkit or simply as drawings on paper.

2.3 Programming in the Finnish core curriculum

In 2014, a new national core curriculum for grades 1-9 was accepted in Finland [13]. It came into force gradually starting in 2016 and introduced seven transversal competences: 1) thinking and learning to learn, 2) cultural competence, interaction and self-expression,

3) self-care and managing everyday life, 4) multi-literacy, 5) digital competence, 6) working life skills and entrepreneurship, and 7) social participation, influence and building a sustainable future. While previous Finnish curricula focused on using IT as a tool [35], the curriculum now highlights the need for also learning about the technology and its underlying principles. In practice, this is visible through the introduction of the fifth part of the transversal competence, digital competence, which is described in terms of four areas: 1) practical skills and own production, 2) responsible and safe ways of working, 3) information management and exploratory and creative work, and 4) communication and networking. Programming is implicitly included as an interdisciplinary trait under the umbrella digital competence, but also explicitly in mathematics and sloyd.

In mathematics, the focus is on logical thinking, problem solving and algorithms, starting with creating and testing step-by-step instructions in grades 1-2, followed by programming in visual environments in grades 3-6 and deepening of programming skills and practice in grades 7-9. Hence, in grades 1-2, programming can be introduced completely unplugged, while computers, robots or other digital devices are needed starting in grade 3.

Sloyd is a subject taught in the Nordic countries and can be described as crafts or handicraft using both soft and hard materials. When introducing programming in this context, new materials and tools are introduced, such as physical computing toolkits, 3D printers and robots. This is hence closely related to the maker culture; a modern version of the DIY culture, including technology-based materials, which has become popular in both formal and informal educational settings [30].

As the curriculum should hold over time, the learning objectives provided for digital competence in general, and programming in particular, are quite non-specific. The lack of concrete examples led to both teachers and school-leaders calling for additional detail on what students are expected to learn and teachers are supposed to teach at different grade levels. As a response, in 2020, the Finnish Ministry of Education and Culture initiated the "New Literacies Programme" (uudetlukutaidot.fi) aimed at developing more detailed and concrete descriptions of the curriculum objectives in three related areas: digital competence, media literacy and programming. The goal is to make it easier for schools to know what to teach and thus guarantee equal learning opportunities to all students.

Programming is described in terms of three areas: 1) computational thinking, 2) exploratory work and production, and 3) programmed environments. The three areas, in turn, include several sub-areas, for which learning outcomes are specified for each grade level (early childhood, pre-primary, grades 1-2, grades 3-6, grades 7-9). Fig. 1 gives a brief description of what is considered a good level of competence in programming at the grade levels considered in this paper (grades 1-6).

When reviewing the areas, it is clear that they have distinct goals. The first one, computational thinking, focuses on the basics of programming: problem-solving, logical thinking, algorithms, concepts and constructs. The second area, exploratory work and production, focuses more on the creative, productive and collaborative aspects. The third, programming environments, does not focus on the students' own programming practice at all, but rather the implications of programming and technology for our society and everyday life. Hence, the areas bear some resemblance to the three framings of CT [26] discussed above.

Most of the PCT activities in school focus on the first area (the basics of programming) and the practical skills mentioned under exploratory work and production. As is seen in the table, students are, however, also expected to learn about design, co-creation, innovation and the role of technology in society and everyday life. National studies [35, 46] indicate that many teachers struggle with teaching practical programming in general, but even more so with the creative and societal aspects. Consequently, students in grades 1-6 are given limited opportunities to learn PCT in general, and more particularly, to engage in the area from a situated and critical perspective.

	The students can...	Grades 1-2	Grades 3-6
Computational thinking	**Logical thinking and processing of information**	> Organize and compare things based on different conditions, such as similar form. > Identify logical operations, such as "and", "or" and "not" > Present the choices and observations made using concepts and concrete tools.	> Organize, compare and present information using technology related concepts and symbols. > Perceive connections between different entities. > Find and describe causal relationships between different phenomena.
	Solving and modelling of problems	> Decompose familiar everyday problems into smaller parts, and try to solve them in different ways. > Tell others about the ways in which a problem has been solved.	> Use different methods and strategies for solving problems and also try create such themselves. > Evaluate solutions using given criteria, such as functionality, readability or effectiveness.
	Basic programming concepts and constructs	> Create step-by-step instructions using simple instructions and loops. > Identify error situations caused by the instructions and try to correct them in different ways.	> Create exact and detailed instructions using repetition and selection. > Look for and correct errors in the instructions and the program code.
Exploratory work and production	**Co-creation processes**	> Present their ideas, listen to others and collaboratively try solutions. > Alternate between different roles when creating programs as a team.	> Describe, in different ways, their own ways of thinking, take the perspectives of others into account and work persistently to achieve the common goal in a programming project.
	Creative production	> Model different things both according to instructions and creatively implementing their own ideas. > Present and share their ideas with others. > Create a digital product containing storytelling or gamified elements using simple programming under guidance or in co-operation with others.	> Use their own observations, measurements and sensors in their products, and combine these with robotics. > Refine existing solutions in a cyclic manner while practicing iterative work, that is, continuous ideation, doing, testing and revising. > Identity computational features in animations and games.
	Programming as a tool for learning	> Process content from other subjects by playfully using and trying out programming related approaches and tools.	> Use programming related tools and approaches for creative expression and own production as well as to explore and explain phenomena in different subjects and multidisciplinary projects.
	Practical skills	> Control a programmable device or a figure in an application..	> Use a visual programming environment and create a program, animation or game with it.
Programmed environments	**Programmed technology in different areas of life**	> Identify and name programmed devices and services they have experienced and encountered. > Familiarize themselves with robotics. > Describe the purpose and operational principles of devices.	> Describe how technological applications can be used, their basic underlying principles and their role in the students' own lives. > Observe the presence of programmed elements, such as robotics and AI, in the surrounding society.
	Impacts of programmed technology in everyday life	> Reflect on the data collected based on their activities in digital environments, as well as the connection between programming and this data collection. > Understand that data collected are stored and give at least one example of what data collected about themselves could be used for.	> Give examples of targeted digital content and ways in which this targeting is accomplished. > Reflect on their own activities and how data collected are used in digital environments..

Figure 1: The learning outcomes for grades 1-6 for the three main PCT related areas according to the New Literacies Programme. (https://uudetlukutaidot.fi).

3 STUDY SETTINGS

While teachers cannot be expected to add new dimensions to their PCT instruction in a situation where many already feel overwhelmed, we wanted to develop a scaffolded model where teachers and students could engage in design and critical discussions together. In this section we present the workshop design, the data collected and the analysis methods used.

3.1 Workshop design

In order to address the lack of design and critical discussions in PCT education at K-12 level, we developed a workshop model that could introduce these aspects to Swedish-speaking students in Finland.

The goal of the workshop is four-fold. First, we wanted to create a concept where teachers and students could be active and learn together, that is, following the ideas of participatory design. This was considered crucial, as teachers have called for professional development where they can experience the teaching situation and thereby get a model for how instruction can be organized [35].

Second, we wanted the workshop to be delivered online. Traditionally, co-design activities with children have been arranged as face-to-face sessions, while there are circumstances where such activities need to be conducted online [32]. In particular, the Covid-19 pandemic raised the need for co-design at a distance [32, 43]. In Finland, Swedish-speaking schools are commonly quite small and geographically dispersed over a large area. In order to make the workshop accessible and scalable, that is, available to as many schools as possible, organizing it online was our only option.

Third, we wanted to focus on the situated and critical framings of CT corresponding to the four areas in the New Literacies framework (Fig. 1): co-creation processes, creative production, programmed technology in different areas of life and impact of programmed technology in everyday life:

- Co-creation processes: e.g., presenting ideas and listening to others while persistently working towards a joint solution.
- Creative production: e.g., modelling and creatively ideating, sharing ideas, and refining existing solutions in a cyclic manner.
- Programmed technology in different areas of life: e.g., identifying and naming programmed devices, describing how these can be used and discussing the role of programmed technology in everyday life.
- Impact of programmed technology in everyday life: e.g., reflecting on how and why data are collected in digital environments and how the data can be used.

Finally, in addition to the technology related learning objectives, we also wanted the model to address the first dimension of the transversal competence, that is, thinking and learning to learn (freely translated from Finnish):

> Thinking and learning skills lay the foundation for the development of other competencies and lifelong learning. [...] This competence is promoted through exploratory and creative ways of working, collaboration, and opportunities to go deeper and focus. Teachers should encourage students to trust themselves and their views while being open to new solutions. [...] Students should be given space to ask questions and be encouraged to look for answers, to listen to the views of others while at the same time reflecting on their own knowledge. [...] Students should learn to use knowledge independently and together with others to solve problems, argue, reason, draw conclusions, and innovate. [...] Innovative solutions presuppose students to learn to see alternatives without prejudice, combine different perspectives and use their imagination to transcend existing boundaries.

To accomplish the four objectives, we designed a model for an online workshop, where students can learn about a new topic and design their own artifact together with their peers. We designed the workshop according to the double diamond model [5], a design process consisting of four phases: Discover, Define, Develop, and Deliver. The name, "double diamond", comes from the model having two parts, each including one divergent and one convergent phase. The Discover and Define phases make up the first diamond, where the problem and context are understood. This diamond is characterized by research, exploration and brainstorming (Discover), followed by identification of the key insights (Define). The Develop and Deliver phases make up the second diamond, where a solution is designed. In this diamond, users first generate a wide range of ideas and prototypes with emphasis on creativity and iteration (Develop), followed by selecting and refining the best solution into a ready-made design (Deliver).

Our resulting model consists of six phases, including four design sprints, which let students move between divergent (exploring and brainstorming) and convergent (focusing, selecting, refining) thinking when creating their own design.

Phase 1: Introduction to the topic
Phase 2: Brainstorming – what do we know about the topic?
Phase 3: Brainstorming – how might we improve a familiar artifact?
Phase 4: Selection – what ideas do we want to keep?
Phase 5: Final design – what does our final artifact look like?
Phase 6: Wrap-up

The model is interactive, with two persons orchestrating the workshop online, and students participating from their own classrooms together with their teacher(s). The workshop is scheduled to last a maximum of 60 minutes, to easily fit the schedules at school. Prior to the workshop, each teacher divides their students into smaller groups, and during the workshop all groups follow the instructions using one computer connected to a video projector. This is important from an accessibility perspective, as we wanted to create a model open to all students regardless of age, previous background and availability of technology at their respective schools. Hence, students are to use pen and paper only. The teachers facilitates the brainstorming, discussion and final design phases in their classrooms.

The workshop model is participatory and collaborative, building on a sociocultural approach [25], which emphasizes the influence of social and cultural contexts on human development and behavior. It posits that individuals do not develop and function in isolation, but rather in interaction with others and within broader social, cultural and historical systems. As such, the sociocultural approach often involves studying how cultural and social factors shape development and behavior, as well as how ch individuals and groups actively shape and are shaped by their social and cultural contexts. As noted in previous research, children commonly develop their digital competence and know-how of digital technologies through intentional or unintentional tutoring by family or friends [38].

3.2 Methodology

In order to address our research questions, this study consists of two parts: 1) a case study of a workshop conducted on the topic "IoT and smart things" and 2) an analysis of the resulting students' designs. In 2021-2022, the workshop was offered online twice to students in grades 1-6 (aged 7-12). During the workshops, the student groups were to design their own smart, Internet connected, version of a familiar everyday artifact: a shoe, backpack, desk and chair, lamp or book. All in all, 1200 students have taken part in the workshop together with 60 teachers.

The collected data consist of anonymised design artifacts uploaded to the joint collaboration board (Padlet) by the teachers after the workshop. Most designs included both text and drawings, while some only included either one. We did not check whether all teachers uploaded all designs, and it is therefore likely that the Padlet does not include all designs created during the two workshops. All in all we have analysed 161 designs (Table 1).

Table 1: Number of designs for the different artifacts per year.

Design artifact	2021	2022	Total
Shoe	12	24	36
Backpack	12	20	32
Desk	12	20	32
Book	12	17	29
Lamp	14	18	32
Total	62	99	161

The designs were analyzed using content analysis in order to categorize the designs and reveal what kind of features, innovations and technological solutions the students have added to their respective thing. Berriman and Guerin [37] point out that while content analysis has traditionally been considered a method to quantify text it can be used as a system exploring both quantitative and qualitative features in a text. Content analysis can also be applied to images and other types of data [14], as it is a "technique for making inferences by objectively and systematically identifying specific characteristics of messages" [18, p. 14]. Thus, content analysis allows for both a qualitative study of drawings and a quantitative exploration of how often certain themes or categories occur.

The first phase of the content analysis involved going through all the designs and identifying coding categories for the students artifacts. This phase resulted in 23 categories: Adaptable, AI, Automation, Cleanliness, Comfort, Communication, Connected, Durability, Energy, Fitness, Food, Keyboard, Light, Screen, Security, Sensor, Service, Sound, Speed, Statistics, Storage, Time, Transportation. When the categories had been identified, all designs were analyzed and coded based on this scheme. Most artifacts were quite complex in functionality and therefore had features belonging to several categories. This was reflected in the coding, by the same artifact being labeled with multiple categories.

4 CASE STUDY

While the workshop model can be used with any topic, we decided to situate our case study in the context of smart things for several reasons. First, as seen above, previous research indicates that IoT and smart things are suitable topics for children. Second, things are a natural and important part of children's everyday lives and it is therefore easy to come up with familiar artifacts to use as a starting point. The teacher randomly assigned each group one of the five artifacts (shoes, backpack, desk and chair, lamp or book) prior to the workshop.

Third, IoT and smart things exemplify an exciting technological area where programming and making can be used to create almost anything, but in order to get to the implementation stage, the user needs to be rather proficient. Implementing such solutions in practice might therefore be too complex, and only few young students take part in that type of experiences at school. Ideating and designing such artifacts can, however, be done using only pen and paper.

The six phases of the "smart things" workshop are briefly described in Table 2. The first phase set the stage for the activities, with us briefly presenting the goal of the workshop, followed by an age-adapted introduction to the topics listed in the table. Before moving on to the next phase, brainstorming and prototyping were introduced.

Next, students were to brainstorm around the topic smart things. As research has shown that teacher presence is important particularly when starting a new design process [51], the teachers were encouraged to facilitate the discussion in their classrooms and help all groups get started. The teachers also sent us examples from the discussions via chat.

The brainstorming session was followed by a short debriefing based on the examples shared in the chat. Next, students were to start creatively ideating features that could make the thing they had been assigned smarter. At this point, they were told to list all ideas that came up in their groups without evaluation. Again, the teacher was active in the classroom to get things started, and also shared some example ideas with us in the chat.

After the two brainstorming phases, the students were to discuss the ideas and jointly decide on what ideas and features to move forward with. Here the teacher had an important role in monitoring the discussions in order to avoid a situation where, for instance, a student would become upset with his/her idea not being chosen.

After a short debriefing, students were given the task to draw and describe their smart thing. This resulted in designs on paper, which were photographed by the teachers and uploaded to the collaboration board. Finally, the workshop was ended with a brief summary and an informal evaluation.

Some issues were raised by the teachers after both sessions. While the older students found the 20 minute introduction interesting, it was considered too long for the younger students, who had a hard time concentrating. The teachers also noted that many students would have needed more time to finalize their designs properly. On the other hand they also acknowledged that 60 minutes is easy to fit into the schedule, while a longer session might make it more difficult for schools to attend at the same time.

5 STUDENT ARTIFACTS

In the following, we will present the main findings from the analysis of the students' designs, one artifact at a time.

Table 2: Outline of the workshop in six phases.

Phase	Topic	Minutes	Outcomes
1. Introduction	Sensors and data collection IoT and smart things Security and privacy Brainstorming and prototyping	20	-
2. Brainstorming	What do we know about smart things? Which sensors or smart/ programmed/Internet-connected things can be found at school?	5	List of things
3. Brainstorming	How can we make the thing smarter? How should it be connected to the Internet? Why should it be connected to the Internet? What sensors and other technology can we use?	10	List of ideas
4. Selection	Which ideas do we want to go forward with?	10	List of ideas
5. Design	What could our design look like? What can it do?	10	Design on paper (drawing + text) Photo for collaboration board
6. Wrap-up	What have we learned? Informal evaluation	5	-

5.1 Smart shoes

Table 3 lists the five most frequently mentioned individual features for the designs of the smart shoes.

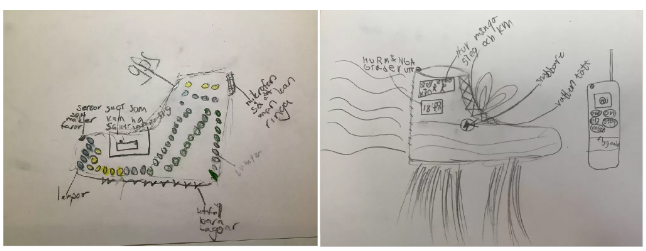

Figure 2: Examples of students' smart shoe designs.

All in all, the most frequently occurring features in the shoe designs were related to adaptability (20/36), sensors (18/36), automation (17/36), comfort (16/36) and security (10/36). Except for the features mentioned in Table 3, students also ideated shoes that, for instance, could be made invisible or include GPS for positioning, weather sensors that could warn if the shoe is not fit for the current weather or sensors that could recognize the user's feet. In addition for the shoes to tie themselves, some students also included automation in the form of a self-walking feature. Despite being heated, the comfort features included, e.g. a drying function and built-in AC. As security measures, students designed reflective shoelaces, built-in surveillance cameras and tazers, corona mask dispensers and retractable spikes to use in slippery weather. Figure 2 shows examples of students' smart shoe designs.

5.2 Smart backpack

The five most frequent design features of the smart backpack are listed in Table 4. When reviewing all backpack designs, the most often included features related to transportation (15/32), services (13/32), comfort (12/32), automation (9/32) and sensors (8/32). Excluding the features mentioned in the table, the students envisioned backpacks with legs or wheels that are service-minded and can help them with their homework, correct assignments, remind them if they forget a book or something else they need for school. In addition, students would like their backpacks to have a built-in umbrella, heater, toilet and fan, while also being able to comfort you when you are feeling sad. The automated features included the backpack packing itself, finding the things to pack on its own and opening/closing the zipper at the push of a button. Finally, students saw the need for the backpack to have a GPS, weather sensor and a sensor that could recognize when its carrier is about to fall. Figure 3 shows examples of students' smart backpack designs.

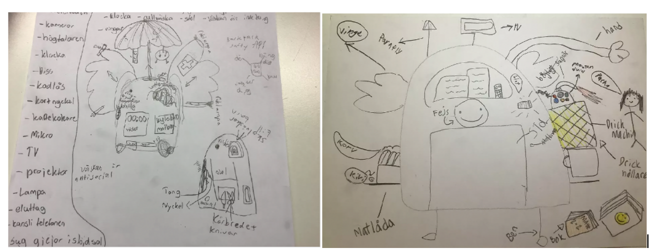

Figure 3: Examples of students' smart backpack designs.

5.3 Smart desk and chair

Table 5 shows the five most frequently mentioned individual features for the combination of a smart desk and chair. Taken together, students most often mentioned features related to comfort (20/33), screen (13/33), services (10/33), transportation (7/33), sensors (6/33) and automation (6/33). In addition to the features mentioned in Table 5, students depicted ideas for the desk and chair offering services such as study help, book lifts and cheating functionality. The desk should also be movable, e.g., by flying or teleportation, and it should

Table 3: The five most frequent individual features in students' designs of smart shoes.

Feature	Category	Mentions/design	Example
Self-tied	Automation	16/36	"If your shoes are not tied two hands can come out and tie the laces for you"
Perfect fitting	Adaptable	12/36	"The shoe recognizes when the foot is inserted and creates the perfect fitting around it"
Faster movement	Speed	8/36	"The rockets are started when you press the button"
Shoe type	Adaptable	7/36	"Shoe transformers"
Heated	Comfort	7/36	"If it is cold a warm fan blows on the feet to make them warm. If it is warm the fan blows cold air."

Table 4: The five most frequent individual features in students' designs of a smart backpack.

Feature	Category	Mentions/design	Example
Flying	Transportation	10/32	"It can fly to school."
Voice assistant	AI	5/32	"It can tell you anything, but only the one carrying the backpack can ask and hear the answers"
Lights	Light	5/32	"It has builtin lights"
Built-in display	Screen	5/32	"You can see what is in the backpack", "You can see what's for homework"
Positioning	Sensor	5/32	"You can find your backpack if its lost"

open, close, and clean itself automatically. Figure 4 shows examples of students' designs of smart desk and chair combinations.

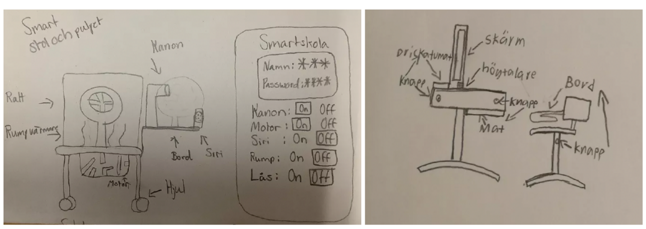

Figure 4: Examples of students' smart desk and chair designs.

5.4 Smart book

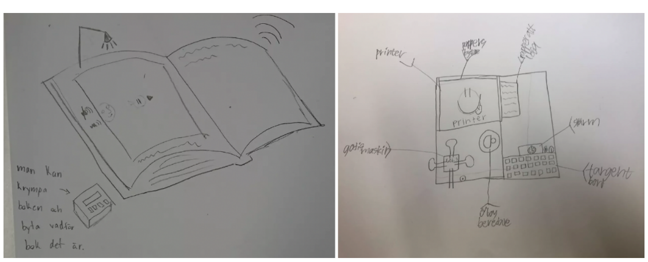

Figure 5: Examples of students' smart book designs.

Table 6 lists the five most frequently mentioned individual features for the designs of the smart book. When reviewing the categories of features exhibited in the designs, we found that students most often mentioned features related to automation (17/29), adaptability (16/29), services (12/29), sound (8/29) and light (6/29). In addition to the features listed in the table, students saw the need for the book to be shrinkable. They also wanted it to be possible to change the language, colors, font size, etc. Students also wanted their books to be service-minded, e.g., reminding them of homework, correcting their assignments, explaining things they do not understand and helping them with homework and exam preparations. Figure 5 shows examples of students' smart book designs.

5.5 Smart lamp

The five most frequently mentioned individual features for the final artifact, the smart lamp, are listed in Table 7. The analysis showed that students, all in all, most frequently had included features related to adaptability (20/32), sound (14/32), sensors (11/32), AI (8/32), services (7/32) and time (7/32) in their designs. Except for the features mentioned in the table, students also wanted the lamp to be a transformer, making it possible to change its shape and size. It should also provide different services, such as entertainment in the form of built-in robot fish or offer reminders, news and money. The lamp could also include a timer. Figure 6 shows examples of students' designs of a smart lamp.

Figure 6: Examples of students' smart lamp designs.

Table 5: The five most frequent individual features in students' designs of smart desk and chair.

Feature	Category	Mentions/design	Example
Built-in display	Screen	13/33	"The desk has a built-in iPad", "The desk comes with a video projector"
Adjustable height	Adaptable	8/33	"The height of the desk and chair can be adjusted"
Heated	Comfort	7/33	"The chair will be heated when in use"
Massage	Comfort	5/33	"If you are sad the chair starts giving you a massage", "If you have a bad posture, the chair will shake and give you a massage"
Snacks and drinks	Food	5/33	"It has a water station and a drink machine", "It can give you food when you are hungry"

Table 6: The five most frequent individual features in students' designs of smart book.

Feature	Category	Mentions/design	Example
Any book	Adaptable	9/29	"Lots of books in one, you can choose and read any book you want"
Automatic bookmark	Automation	8/29	"It keeps track of the page you are on"
Talks and reads	Sound	8/29	"It reads itself", "It has a narrator voice if you don't feel up to reading aloud yourself"
Built-in lights	Light	6/29	"Lights for when it's dark"
Automatic page turns	Automation	6/29	"It has a page turning function", "It turns the page when you touch it"

Table 7: The five most frequent individual features in students' designs of smart lamp.

Feature	Category	Mentions/design	Example
Color choice	Adaptable	14/32	"It can be any color you want"
Motion activation	Sensor	10/32	"If you dance it starts blinking in different colors", "It turns on when you walk by"
Voice assistant	AI	8/32	"You can talk to it to control it"
Music	Sound	7/32	"It can play music"
Talks to you	Sound	7/32	"It can talk to you, encourage you and contribute to a positive atmosphere"

6 DISCUSSION

The two previous sections, presenting the case study and the student artifacts, bring light on our two research questions. While the case study exemplifies how design and societal aspects can be introduced at K-12 level at scale, the analysis of the students' designs give insight into their ideas and the features and characteristics included in their designs.

The workshops were quite successful, considering the number of students and teachers taking part in them. All student groups managed to create their own design, and a majority of them were successfully uploaded to the online collaboration board. Our findings indicate that students had the most varied ideas for the backpack and the shoes, which is quite understandable as these artifacts can be seen as the most versatile and follow the students throughout the day. Hence, it may be easier to come up with new ideas for such things. The designs also clearly highlight problems that students experience in their everyday life, for instance, having to tie their shoelaces, carry their backpack and clean their desk. Moreover, many of the "crazier" ideas indicate that students were being creative and brainstormed freely during the workshop. One possible limitation to the artifact analysis is that the coding was carried out by one author only. However, as close to all artifacts were labeled with multiple categories based on all the features found in the design, the chance of another person ending up with a notably different categorization was considered low.

Compared to other initiatives on smart things design for children, which include, e.g., physical tool-kits for implementation and testing (e.g., [15]), students following our model only create a design on paper. This does, however, mean that the workshop takes less time, does not require any physical equipment or technology, can be more scalable and might be easier for the teachers to repeat on their own.

Nevertheless, as noted in the section presenting the case study, teachers raised several issues related to time. First, the introduction was deemed too long for the younger children, raising the need for having separate workshops for different grade levels. This is crucial as age, development level and needs are important aspects to consider when involving children in design of interactive technologies [48]. Having separate workshops would also be beneficial from a curricular point of view, as the learning objectives (Fig. 1) are different for students in grades 1-2 and grades 3-6, and thereby difficult to cover in one single workshop.

Moreover, teachers noted that more time would have been needed for students to finish their artifacts properly. This is understandable, as designing a smart thing is a complex and lengthy process [43]. Increasing the length of the workshop might, however, have a negative effect on the potential for scalability, as longer sessions may be difficult to fit into many schools' schedules at the same time.

In addition to the teachers' reflections, we have identified one main "lesson learned" of our own. Although we discussed privacy and ethical aspects of IoT and smart things in the first phase of the workshop, the students focused mostly on design (situated CT) while only a few reflected on the ethical and societal aspects of their designs (critical CT). This might be due to several reasons. One likely reason is that the workshop schedule did not leave any time for students to consider such questions. Another probable reason is that the short introduction was not enough to communicate the importance of these aspects. Also, students in grades 1-6 may not have a sufficient understanding of the potential negative consequences of big data and IoT to reflect on them, in particular in relation to their own designs.

Previous research has, however, shown that, for instance, middle school students can become "critical users and ethical designers of technology" [9]. One solution could therefore be to create additional material that teachers can use after the workshop to continue the work with their students, both for refining the designs and for discussing the critical stance related to technology in general, and their designs in particular. Opportunities and resources for follow-up work in the classrooms can also make it possible to keep the workshop length at 60 minutes. Another option is to make the workshops more focused, having separate workshops for design and ethical/societal perspectives respectively. This will leave more time for covering the situated and critical aspects of CT, while also making it possible to connect the two to different contexts or topics. At the same time, additional material and/or separate workshops could make it easier to cover learning objectives related to programmed technology and its impact in everyday life (Fig. 1). An area that could be particularly well suited for addressing these objectives and the critical framing is AI and machine learning [28].

7 CONCLUDING REMARKS

In this paper, we have presented a scalable, scaffolded online model for a workshop where students in grades 1-6 and their teachers are introduced to design of new technological solutions. Through a case study with roughly 1200 students and their 60 teachers on the topic of IoT and smart things, we have described how the workshop was arranged in practice. In addition, we have brought light on the breadth of students' designs and ideas.

While the goal of helping students design their own artifacts was met, more time would have been needed in order to give students sufficient know-how to ponder the societal and ethical aspects related to technology design and use. This, naturally, also needs to be done at an appropriate level, taking into account both the age of the students and curricular requirements, in order for the workshop to address the learning objectives of all students. The results therefore suggest creating separate workshops for 1) different grade levels and 2) covering the situational and critical framings of CT respectively. Moreover, additional material for follow-up work in the classroom can be helpful for the teacher to continue the discussion after the workshop.

The paper contributes to the current knowledge base in two ways. First, it provides a model for introducing emerging technologies and design to teachers and students at a scale. Second, the study shows that young students can come up with new ideas in a complex field even in a short amount of time, provided that the design context is familiar to them. Third, the scaffolded, low-tech workshop gives teachers a low-treshold entry point and model for discussing emerging technologies with their students. The major contribution of the paper is thus the case study itself, which serves to illustrate how complex ideas and new technology can be introduced using simple means to young students online.

8 SELECTION AND PARTICIPATION OF CHILDREN

No children were specifically sampled to take part in our case study. Rather, the students involved where of the teachers wanting to take part in the workshop. No child was visible to the researchers and all designs were anonymised when the teacher added them to the padlet.

ACKNOWLEDGMENTS

This work was supported by the Marcus and Amalia Wallenberg Foundation.

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