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Research paper

# Computational empowerment in practice: Scaffolding teenagers' learning about emerging technologies and their ethical and societal impact

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ABSTRACT

Whereas computational empowerment is well established in child–computer interaction research, less effort has been made to integrate this approach in practice. Building on four existing principles in child–computer interaction, namely *Closeness, Embodied Learning, Design Process* and *Decoding*, we explore how computational empowerment can be scaffolded in practice. This study was part of an interdisciplinary research project exploring emerging technologies in education (CEED). We involved 9 teachers and 26 students (14–15 y) in Denmark in teaching about machine learning and augmented reality. In the article we develop a framework for applying computational empowerment in formal educational contexts. Based on the study, we found that computational empowerment builds on distinct layers which are these four principles. Specifically, merging the principles *Closeness* and *Embodied Learning* can increase student engagement and motivation in the activities; in addition, *Decoding* and *Design Process* are key principles for promoting student awareness of the societal impacts of emerging technologies. Based on qualitative data from this intervention, we discuss the opportunities and challenges for child–computer interaction in moving toward computational empowerment in practice.

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## 1. Introduction

This paper describes how computational empowerment is applied in practice by the use of four principles drawn from the child–computer interaction (CCI) literature. Research in CCI has long acknowledged the need for computational empowerment in technology education (Blikstein, 2013; Dindler et al., 2020; Iivari & Kuutti, 2018; Kafai et al., 2020; Katterfeldt et al., 2015; Tissenbaum et al., 2021; Van Mechelen et al., 2021), that is, the requirement to support children and young people in making informed decisions about the role of technology in their lives (Iversen et al., 2018). For example, Schelhowe (2013) describes the concept 'Bildung' as a means of strengthening children's self-cultivation in digital making in the classroom and to provide them with the resources to become digital citizens through processes of digital fabrication. Dindler et al. (2020) highlight the need to provide children with means to engage with values embedded in technologies such as ethical discussions about humans' democratic rights, civic engagement, and people's agency as users and co-creators of a future digitalized society. Kafai et al. (2020) call for initiatives that would "pull[ing] back the curtain of the technological mechanisms" in order to make visible the inequalities that underlie existing computational systems.

Recently, this demand has also gained relevance on the political level. For instance, the Informatics for All coalition has called for the integration of informatics into other disciplines with the aim of teaching students about significant applications of informatics so as to include their social impact and relevance to the future of work and life in general (Caspersen et al., 2022). At the same time, international organizations such as UNICEF (2019) and OECD (Vincent-lancrin & Van der Vlies, 2020) have argued that transparency and explainability are a requirement in all technologies, that is, that meaningful information needs to be provided to further the understanding of artificial intelligence (AI) systems, user interaction, and how they affect society. These political missions resonate with the CCI literature on computational empowerment (Dindler et al., 2020; Iivari et al., 2021; Kafai et al., 2020; Tissenbaum et al., 2021).

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Both the CCI literature and political recommendations aim to empower children in regard to digital technology. Less attention has been paid, however, to how this is actually to be achieved in practice. In formal education, learning activities and experiences with technology tend to focus on teaching STEM-related concepts (e.g. physics, mathematics, coding skills, etc.). In so doing, computational thinking is emphasized (Anwar & Bascou, 2019; Benitti, 2012) over, for example, the societal and ethical implications of these technologies (Charisi et al., 2020). But especially when introducing emerging technologies to students, a focus on the societal and ethical implications is critical. Emerging technologies are characterized by functionalities leading to novel and as yet unexplored forms of interaction between people and with the world (Rotolo et al., 2015). Furthermore, the future impact of emerging technologies on society is highly complex and difficult to predict. These characteristics pose both a need and a challenge to educate future generations in understanding their complexity and potential impact.

This study is part of the interdisciplinary research project, Computational Empowerment for Emerging Technologies in Education (CEED, 2020–2024). This involves developing new educational practices that balance the technological and societal aspects of emerging technologies and engage students in abstract thinking, hands-on construction, and redesign activities. Based on such approaches and our prior research in children's design-based learning in technology (Schaper et al., 2019; Smith et al., 2015), we aimed to develop new learning activities and tools that would address the particular challenges and characteristics of emerging technologies (Dindler et al., 2020; Iversen et al., 2019, 2017). To do so, for this study, we merged policy recommendations with the goal of scaffolding an academic trajectory of computational empowerment in practice. In the educational literature, the term "scaffolding" is used to refer to situational support for learners in the zone of proximal development (Belland, 2014). In other words, our goal was to explore key principles that could support students' learning about emerging technologies and their societal impact. Here, we use the term principles as a metaphor for the mechanisms that are embedded in learning activities (Rogers et al., 2000). We scaffolded computational empowering by building on principles well established in CCI research that allowed us to explore and gradually construct distinct layers of computational empowerment. The principles *Closeness* and *Embodied Learning* as they emerge from the CCI literature stem from well-established child development research in relation to students' engagement and meaning-making of abstract concepts (Freiler, 2008; Rogoff, 1998). In contrast, *Design Process* and *Decoding* are fairly recent principles in CCI literature that emerged in the context of digital fabrication in education (Blikstein, 2013; Dindler et al., 2020). Whereas the principle *Design Process* focuses on the digital making process, *Decoding* concerns students' development of specific vocabulary and knowledge about emerging technologies which they can use to express their awareness of these societal impacts. At the same time, the *Decoding* concept derives directly from Schelhowe's work on Bildung (Schelhowe, 2013).

The paper is structured as follows. In the background section, we first give an overview of current teaching practices of learning for emerging technologies. We then explain how the four core principles *Closeness*, *Decoding*, *Design Process* and *Embodied Learning* connect to the existing literature and how they were used as a means to scaffold computational empowerment in practice. In the third section, we describe our methodology, which was based on a design-based research approach (Bell et al., 2004), the intervention procedure, and methods for data collection and analysis. In the fourth section, we present our findings and show how the four principles unfolded in different learning activities. Our findings built on the analysis of students' self-perceptions and teachers' feedback on learning activities during a five-day research intervention conducted in a public primary school in Aarhus, Denmark. Finally, we discuss the opportunities, challenges and future directions for integrating the four principles in learning activities for emerging technologies.

## 2. Background

### 2.1. Trends in technology education in K–12

Due to the ubiquity of technology in society, learning about emerging technologies has become an urgent agenda in the K–12 school curriculum (Touretzky et al., 2019). Technologies such as machine learning (ML) and augmented reality (AR) are predicted to have a profound impact on society and on the labor market, with close to half of current jobs at risk of radical transformation (*OECD Employment Outlook 2019*, 2019). This evolution is mirrored by the growing interest in teaching children and young people about emerging technologies. These developments have opened a novel research field primarily concerned with two main directions of technology education.

First, a large body of research is focused on supporting children's understanding of technological aspects of emerging technologies with the aim of preparing students for graduate studies and for work in the computing industry (Anwar & Bascou, 2019). In this regard, several scholars have investigated educational approaches to teaching students about technological concepts such as computational thinking (Angeli & Giannakos, 2020; Brennan & Resnick, 2012; Grover & Pea, 2013).

Second, there is an increasing trend to engage students in critical reflection on the ethical and societal implications of emerging technologies as part of the agenda in K–12 education (Charisi et al., 2020). Maas and Hughes (2020) stress the need to provide students with digital skill sets that can help them retain control over their use and consumption of AR technologies. Druga et al. (2019) point to the importance of teaching children about intelligent technologies by reflecting on aspects that go beyond the technical features. Anwar and Bascou (2019) highlight the role of the educator in helping students understand the technological groundings behind AI research as well as the limits and potentials of it. Finally, Touretzky et al. (2019) propose guidelines that also include critical reflections on how AI applications can impact society in both negative and positive ways.

New research agendas have tended to address emerging technologies at large, focusing on the need for explainable, transparent, ethical characteristics in technological innovations (Abdul et al., 2018; Akata et al., 2020). Such characteristics of emerging technologies are difficult to teach to children because they are abstract concepts. Appropriate learning activities and tools should support students in critically reflecting on these characteristics and their ethical and societal impact.

Responding to this need, researchers (Lin & Van Brummelen, 2021; Long & Magerko, 2020; Sanusi & Oyelere, 2020; Tedre et al., 2021; Touretzky et al., 2019; Van Mechelen et al., 2022) have presented relevant guidelines and design considerations for learning activities for AI/ML technologies. Several of these recommendations are distilled from literature reviews. For instance, Long and Magerko (2020) suggest several design considerations to support AI developers and educators in generating learner-centered AI. The considerations are organized in a conceptual framework based on five key concepts, namely *What is AI?; What can AI do?; How does AI work?; How should AI be used?; and How do people perceive AI*? Tedre et al. (2021) highlight potential and pitfalls in teaching about ML. Sanusi and Oyelere (2020) propose strategies for teaching about ML approaches based on active

learning, participatory learning and design-oriented learning. For instance, the authors highlight participatory learning as a way of "creating positive experiences that makes children have the feeling of being the author of one's actions in the world". Other scholars have worked with participatory research approaches to define learning activities for AI/ML. For instance, Touretzky et al. (2019) collaborated with AI experts and teachers to develop guidelines for learning about AI in K–12. Lin and Van Brummelen (2021) organized co-design workshops with teachers to identify opportunities to integrate AI education into the curriculum. Yet these design recommendations are often formulated in general terms and not easily translatable into concrete "principles" for learning activities. This presents challenges for teachers and educators who wish to develop learning activities for their students and make them shareable and adaptable to different contexts and needs.

#### *2.1.1. Teaching about ethical and societal implications of emerging technologies*

Scholars have proposed a range of learning activities that foster students' critical thinking about the ethical and societal implications of emerging technologies. These include unplugged activities, hands-on activities with technology tools, and design-driven activities.

The first strategy, unplugged activities, includes studies that propose activities without the use of any digital technology to engage students in discussions of the societal and ethical implications of emerging technologies, typically through a combination of creation and reflection. For instance, students were asked to analyze social media technologies and their stakeholders (DiPaola et al., 2020), discuss real-world machine learning dilemmas (Bilstrup et al., 2020), and reflect on the differences between AI, humanity, and sociocultural traditions as well as the limitations of each, using food practices as conversational props (Schaper et al., 2020). When students were asked to create artifacts in order to examine the human implications and societal impacts of emerging technologies, scholars have proposed activities in which students were asked to conceptually design ML systems (Bilstrup et al., 2020) and to imagine aspects they would like to teach to an AI assistant (Druga et al., 2019).

A second strategy, hands-on activities with technological tools, includes studies that allow students to engage with different types of data (Estevez et al., 2019; Hitron et al., 2019; Kaspersen et al., 2021a, 2021b; Lechelt et al., 2020; Yap & Lee, 2020). These studies presented various paths for engaging students in the activities. For instance, Yap and Lee (2020) used an interactive AR book to make students aware of their digital footprint. Lechelt et al. (2020) used a toolkit to sense students' data about their bodies and environment. Hitron et al. (2019) used block-based programming activities to collect teenagers' opinions on how AI affects the lives of ordinary people, as well as a gesture-recognition research platform that aims to make machine learning more transparent and understandable to children. Kapersen et al. (2021) presented the machine learning machine, a tangible user interface which enables students to create their own datasets, to iteratively build and test ML models. The same authors (2021) proposed a tool called VotestratesML, which allows students to build models and make predictions based on real-world voting data.

A third strategy to engage students in learning activities about the ethical and societal impacts of emerging technologies is design-oriented learning activities. Characteristic of such studies is that they allow students to create alternative scenarios and reflect upon related problems in different scenarios (Dunne & Raby, 2013; Hardy & Myers, 2018; Skinner et al., 2020; Tamashiro et al., 2021). For instance, Skinner et al. (2020) proposed a co-design activity to create an artificially intelligent librarian that is "fair" and thus facilitated discussions of the benefits of personalization vs. issues of privacy and security, potential biases, and fairness. In contrast to this approach, Dunne and Raby (2013) used speculative design to create tangible products and fictional scenarios that serve as catalysts for discussing contemporary issues by "collectively redefining our relationship to reality". Hardy and Myers (2018) and Tamashiro et al. (2021) used design fiction to introduce students to emerging technologies and redesign activities, with the aim of encouraging the students to analyze how their created artifacts could potentially impact both individuals and society.

Despite this relevant and promising work, there is an urgent need for more balance between activities in which students can design and construct technology and activities in which they can analyze, reflect on and deconstruct existing technology (Dindler et al., 2020). In this regard, Van Mechelen et al. (2022) highlight that teaching practices about emerging technologies in K–12 education generally lack a humanities perspective and insufficiently address design aspects as well as ethical and societal implications. Other scholars have furthermore stressed the challenge of engaging teenagers in design activities for technologies (Little et al., 2016). These challenges point toward the need to explore strategies that can scaffold computational empowerment in practice, i.e. support teenagers' engagement in both the reflection upon and the creation of alternatives for emerging technologies.

### *2.2. Principles for engaging teenagers in learning about emerging technologies*

In the study reported in this paper, we focused on exploring strategies to engage teenagers (i.e. 13-to 19-year-olds) in (1) taking part in learning activities; (2) interweaving learning content about technological knowledge and the ethical and societal implications of emerging technologies; (3) providing opportunities to design alternative future visions for emerging technologies. To address these goals, we explored how to scaffold computational empowerment in practice using the four learning principles *Closeness, Embodied Learning, Design Process* and *Decoding*. This section describes how these four principles connect to the CCI literature and to technology education.

#### *2.2.1. Closeness bridges teenagers' everyday experiences and previous knowledge*

We used the concept ***Closeness*** as a principle for engaging teenagers in learning activities about emerging technologies. Specifically, this concept connects with the goal of motivating teenagers in activities, themes and contexts that are close to their everyday experience, yet at the same time help them to build their new knowledge on concepts that are familiar to them (Rogoff, 1998). Previous research in CCI has reported specific challenges in engaging teenagers in design research (Fitton & Bell, 2014), such as their short attention span, low motivation, critical behavior, and unpredictable attendance during the activities (E. Mazzone et al., 2008). We named this principle *Closeness*, which addresses these challenges by providing contexts with "thick authenticity", i.e. activities that are personally meaningful to the students and link to important and interesting aspects of the world beyond the classroom (Shaffer & Resnick, 1999). For instance, prior work has explored the principle *Closeness* by investigating the usefulness of a number of different strategies to engage teenagers in design activities, such as diaries (Toth et al., 2012), teen personas (Horton et al., 2012), comic boarding (Moraveji et al., 2007), audiovisual narratives (Malinverni et al., 2021), and performance (Giaccardi et al., 2012). Other scholars have focused on contexts and themes that are close to students' everyday lives, such as social media (DiPaola et al., 2020),

friendship (Depping et al., 2018), experiences during childhood (Schaper & Pares, 2022), and cultural family traditions (Schaper et al., 2020). At the same time, our understanding of the principle *Closeness* builds upon Iversen et al.'s (2013) theoretical account of teenagers' hierarchy of motives. Iversen et al. distinguish between "meaningful motives" and "dominant motives". Meaningful motives refer to themes that connect with teenagers' interests and preferences and shape their engagement in a particular task; dominant motives refer to activities that are central and important in teenagers' lives. In this study, we explored how the principle *Closeness* can support students in "thinking about problems and issues, and which provide for evaluation that is meaningfully related to the topics and methods being studied" (Shaffer & Resnick, 1999). At the same time, we aim to investigate how dominant motives may shape students' attitude toward their use of emerging technologies.

*2.2.2. Embodied learning engages teenagers in meaning-making of abstract concepts*

The concept ***Embodied Learning*** can be considered another core principle to support teenagers' understanding of emerging technologies. Previous research has highlighted its potential to support students' learning about abstract concepts (Malinverni & Pares, 2014) and social–emotional learning (Schaper & Pares, 2022). Both these aspects are crucial when teaching teenagers about emerging technologies, since their future impact on society is highly complex and requires the capacity to understand the impact of other people's experiences and perspectives. Previous work has stressed the potential of physical activity and specific gestures as a means for learning abstract concepts through concrete experiences (Freiler, 2008; Glenberg, 2010; Goldin-Meadow, 2011). Such theoretical approaches are supported in the field of cognitive science, for instance by Barsalou's grounded cognition approach (Barsalou et al., 2003). Barsalou suggests that the same neural patterns are involved when we are physically enacting and then mentally recalling a particular movement. Phenomenological frameworks based on Merleau-Ponty's work (Antle, 2009; Larssen et al., 2007; Loke et al., 2013; Moen, 2005) claim that perception is an active process of meaning construction which involves large parts of the body. From a pedagogical perspective, this argument connects with the theoretical frameworks of Piaget and Papert, who believed that the cognitive development of children in terms of knowledge and conceptual changes is influenced by their living experience as result of people's action-in-the-world (Ackermann, 2004). Building on this theoretical framework, scholars have highlighted the potential of embodied learning activities to support students' capacities in perspective-taking and empathy (Antle et al., 2013; Lyons et al., 2012; Malinverni et al., 2018; Roberts et al., 2014; Schaper et al., 2018). These studies also showed how the principle of *Embodied Learning* supports students' meaning-making of abstract and complex concepts through bodily enactments and social interactions with other students in the world. However, current pedagogical approaches are often challenged when it comes to emerging technologies, which are characterized by complexity, pervasiveness, and unpredictable future implications for the society at large. Thus, in this study, we were interested in exploring learning activities about emerging technologies that make their characteristics experiential, understandable and graspable to children and young people and extend beyond a focus on the technologies in themselves, as a part of their basic education.

*2.2.3. The design process helps teenagers to understand the design cycle*

Another strategy highlighted in the literature (Dindler et al., 2020; Gajda et al., 2017; Vygotsky, 2004) is the principle we named ***Design Process.*** We understand this as a way to express and materialize perspectives through the making of artifacts, alternating between divergent and convergent thinking. In other words, the principle focuses on the design process itself. In this regard, Dindler et al. (2020) highlight the need for students to understand how a design process works, i.e. to understand the nature of iterative design processes that are driven by research and continuous reflection. The authors specifically stress that students must develop their ability to work with complex problems and to argue for the choices made in their design process. Furthermore, we build our definition of the principle *Design Process* on the work of Gajda et al. (2017), who argue that the development of novel ideas and behaviors is achieved through divergent thinking, i.e. the ability to produce flexible and original ideas through exploring many possible solutions, in contrast to convergent thinking, which can be used to evaluate the appropriateness of novel behaviors, ideas and products. Hence, in our study, we focused on how the principle of *Design Process* leverages teenagers' understanding of different aspects of the design process, i.e. students' capabilities for creative creation leading to the ability to perform the different steps of an iterative design process.

*2.2.4. Decoding supports teenagers' analysis and reflections during design-oriented learning*

Dindler et al. (2020) proposed distinguishing between the concepts of "coding and decoding" in design-oriented learning activities. The concept "coding" describes how students engage in the construction and design of digital artifacts. In contrast, the concept "decoding" describes activities that involve students in analyzing and reflecting on technology that is designed by other people. This second concept is specifically relevant to teaching practices with teenagers, because from the age of 11 children are at a stage in which they start to think abstractly and are able to reason about hypothetical problems (Perinat & Lalueza, 2007). Thus, the concept ***Decoding*** can be considered a core principle for supporting teenagers' understanding of emerging technologies. Specifically, teenagers should be encouraged to understand the intentions and values of stakeholders in the design of the technology and to discuss its possible impact on society. Most design-oriented learning activities, however, tend to focus on "coding" rather than "decoding" practices. Originally, design-oriented learning was used in K–12 education to focus on students as builders of their own knowledge (Papert, 1980). This pedagogical strategy connects with students' interests and perceived ownership of learning (Roth & Lee, 2006). At the same time, the approach offers students opportunities to create artifacts that illustrate solutions to the problems that they consider to be meaningful (Krajcik & Blumenfeld, 2006). Previous studies in digital fabrication have shown how this approach allows children to creatively work together in order to tinker and develop solutions for real-world challenges (Smith et al., 2015). Vartiainen (2014) stresses that a design-oriented learning approach can enhance students' chances of becoming active agents in their own lives and learning in settings far beyond the classroom. In the context of education about emerging technologies, Lai and Chan (2014) and Mariescu-Istodor and Jormanainen (2019) employ a design-oriented learning approach to teach students about ML. Lai and Chan showed that students had a better understanding of the ML concepts and participated more actively in the context of the classroom activity. Mariescu-Istodor and Jormanainen presented a study where the students designed and successfully implemented a ML method in the system. However, we argue that while these approaches can improve learning, they are still too often focused on technological characteristics and lack a humanities perspective capable of integrating reflective

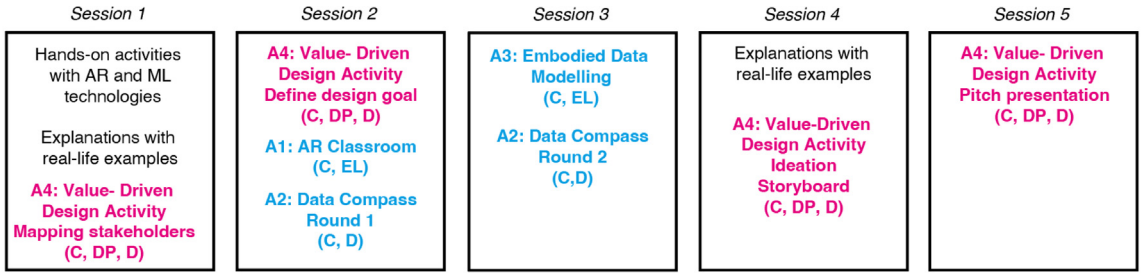



**Fig. 1.** Overview of research intervention and learning activities and the principles that unfolded. The principles are labeled as followed: C = Closeness, EL = Embodied Learning, DP = Design Process, D = Decoding. The Value-Driven Design Activity was connected across four out of five sessions (red). The content used in data-driven activities built upon each other (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

practices on the opportunities and risks related to emerging technologies. Thus, in this study, we aim to address this challenge by interweaving different competence areas related to the subject technology comprehension into the learning activities, including digital literacy and computational thinking (Dindler et al., 2020).

Our overview of the relevant work has described the four principles of *Closeness, Embodied Learning, Design Process and Decoding*. To our knowledge, these principles have not been used together to scaffold computational empowerment into practice. Thus, our main objective in this study is to explore how these principles unfold during a research intervention aimed at teaching teenagers about emerging technologies. In the next section, we will detail our methodological approach for the intervention and give an overview of the workshop procedure and activities.

## 3. Methodology

The overall framework for this study is based on a design-based research approach (Bell et al., 2004) We carried out an empirical study on students' learning about emerging technologies during a five-day research intervention in an everyday setting, a public primary school in Aarhus, Denmark. Based on a two-month co-design process involving nine teachers, we developed a series of learning activities focusing on the technological aspects and societal impacts of machine learning and augmented reality technologies. We engaged 26 eighth-grade students (aged 14–15) in the research intervention, to test and explore the activities with their teachers and the research team.

The main goal of the intervention (Fig. 1) was to explore how we can scaffold the development of students' computational empowerment in their design-oriented engagement with emerging technologies. Therefore, we focused on teaching technological knowledge and the related societal impacts in parallel. We combined analog activities (e.g. Data Compass) with embodied learning activities (e.g. AR Classroom and Embodied Data Modeling). In addition, we integrated this focus in a Value-Driven Design Activity that was carried out across four out of five sessions. This approach provided opportunities for the students to understand both the foundations and the ethical and societal implications of emerging technologies. In this intervention, we especially focused on technologies based on ML and AR. The learning activities were framed to engage the students critically and curiously with the construction and deconstruction of emerging technologies. At the same time, we aimed to support the students' development of skills and knowledge with which to redesign technologies that are attuned to visions for sustainable global futures.

In our study, we were particularly interested in understanding which opportunities and challenges practitioners would face when designing learning activities to scaffold computational empowerment in practice. To achieve this goal, we observed how the principles described above unfolded in the different learning activities.

### 3.1. Participants

26 students (f = 13, m = 13) aged between 14 and 15 years from a public primary school in Aarhus, Denmark, participated in the intervention. Ethical approval was granted by our university's institutional review board, and informed consent was obtained from the students' legal guardians. The research team consisted of five scholars with a focus on digital design and four scholars with a computer science background (f = 5, m = 4). 32 pioneer teachers and 2 special consultants from Aarhus municipality in Denmark worked as our main research partners throughout the project. Specifically, 9 pioneer teachers were closely involved in this research intervention. Three teachers (f = 1, m = 2) eventually formed a core group who collaborated more intensively with the researchers in this intervention (for more detail, see the section on selection and participation). Through this practice-based process, we generated experiences and insights that allowed us to analyze how the learning activities unfolded.

### 3.2. Data collection and analysis

For this paper, we focused on three main data sources collected during and immediately after the intervention: (1) notes and transcripts of video recordings from feedback sessions with the researchers and three core teachers involved in the intervention, (2) short group interviews with all 26 students before the end of the intervention, and (3) semi-structured interviews with 8 students one week after the intervention. For the analysis of this intervention, we employed a qualitative approach oriented to identifying how the four principles *Closeness, Embodied Learning, Design Process* and *Decoding* unfolded within the various activities we conducted during the research intervention. To this end, we held a feedback meeting with the teachers after each session in which we discussed overall impressions of the session, strengths and weaknesses of the learning activities, and ideas for possible improvements. Furthermore, we assessed the students' self-perceptions and the teachers' feedback about the learning activities. For the intervention, we divided the students into eight groups of 3 to 4 children. After the final session in the intervention, each group was interviewed (15 min) by one of the teachers involved in the intervention. The interview questions concerned the students' overall impressions of the activities and their self-perceived learning. The questions are:

(1) What have you learned about machine learning and augmented reality through this course?
(2) Where have you learned the most and why? What did you learn the least from and why?
(3) How did you experience the different kinds of activities?
(4) Can you briefly tell us what your project idea was about?

**Table 1**
Template approach and codes used for the principle Closeness.

| Code | Description | Example | Level-1 | Level-2 | Level-3 |
|---|---|---|---|---|---|
| Closeness | A way to spark students' interest by exposing them to familiar concepts and topics relating to their own world. | Interview Group 1<br>"R1 (11'46): Hvad for en dag kan du mest huske? [What day do you remember the best?]<br><br>(...)<br>R2 (00'22): I think it was to translate text. "(looking at his group member)"<br>R1 (00'28): Yeah, it is just the same. I guess we do that Google Translate think, where we can like relate to it, because we use it sometimes."<br><br>**(level 2)** | **Familiar**<br>Concepts and topics that are familiar to a person | **Meaningful**<br>Enduring interests and preferences that shape a person's engagement in particular activities<br><br>(Iversen et al., 2013) | **Dominant**<br>Types of activities that are central and most important to a person's life, reflecting their primary institutional engagement. For school children, dominating motives are typically connected to the exploration of roles and being like the adults.<br><br>(Iversen et al., 2013) |

**Table 2**
Template approach and codes used for the principle Embodied Learning.

| Code | Description | Example | Level-1 | Level-2 | Level-3 |
|---|---|---|---|---|---|
| Principle | | | | | |
| Embodied learning | A way to help students make meaning from active experiences that require both physical and mental actions. | Interview Group 2<br>"student R2 (03'38): Yeah, the same things and when we did the thing out there like when we were standing with the papers. And when we did that quiz thing, and it came up on the smartboard. I cannot remember what it was called."<br><br>(level 2) | **Tangible manipulation** refers to the material representations with distinct tactile qualities, which are typically ***physically manipulated*** in tangible interaction. (Hornecker, 2010) | **Spatial interaction** refers to the fact that tangible ***interaction is embedded in real space*** and interaction therefore occurs by movement in space. (Hornecker, 2010) | **Embodied facilitation** highlights how the ***configuration of material objects and space affects*** and directs emerging ***group behavior.***<br><br>(Hornecker, 2010) |

The interviews were video-recorded by the teachers. Furthermore, 8 students (f = 3, m = 5) were interviewed in groups of four (30 min) one week after the intervention. These interviews were conducted at the school by two researchers and focused on the opportunities and challenges that the students experienced during the learning activities. For instance, "You had different ways of learning about the technologies — some more physical/active and others more working at the desk. How did you experience those two ways?"

Specifically, we aimed to identify which principles unfolded in each activity and which issues could have impacted the students' learning experiences. The students were selected by the class teacher based on their interest in participating and their ability to carry out the interview in English (due to the two researchers' international background). The interviews were video-recorded and transcribed verbatim.

For the analysis, the video materials of the student interviews were transcribed and the group interviews were translated into English. The transcriptions were then analyzed using NVivo software and using a template approach (Crabtree & Miller, 1992), i.e. key codes for the principles were deductively defined based on theory derived from the CCI literature. At the same time, we inductively developed key codes for the opportunities and challenges related to the learning activities. These codes were used as a matrix for the data analysis.

The code investigating the principle of *Closeness* was derived from CCI literature grounded on developmental theories (Iversen et al., 2013). We distinguished between non-engagement (level 1), meaningful motives (level 2), and dominant motives (level 3). In this regard, we aimed to extrapolate when a context or theme became personally meaningful to students and to what extent it shaped their attitude toward their use of emerging technologies (Table 1).

For the principle *Embodied Learning*, we used Hornecker's (2010) *Tangible Interaction Framework* and divided the concept into three levels: (1) tangible manipulation, (2) spatial interaction, and (3) embodied facilitation (Table 2). Distinguishing between these three levels allowed us to understand the degree of bodily involvement and interaction within a specific space and with other participants of the activity. It is important to note that in this category the three levels do not represent a hierarchy from low to high student engagement in the activity; rather, they highlight different ways of engaging the students. Their type of embodiment depended on the specific goal of each activity, e.g. taking the example above, individual explorations of space (level 2) or a meaningful collaborative activity.

Our definition of the principle *Design Process* stemmed from CCI research on educational psychology on design-making and creativity (Gajda et al., 2017). We focused on the students' understanding of a design process (Table 3), i.e. moving from their capacity to generate ideas during the design tasks (level 1) toward the capacity of divergent thinking (level 2) and the level of appropriateness of their design ideas for the proposed context (level 3).

For the principle of *Decoding*, we made a distinction between the degree of the students' technical understanding of emerging

**Table 3**
Template approach and codes used for the principle Design Process.

| Code | Description | Example | Level-1 | Level-2 | Level-3 |
|---|---|---|---|---|---|
| Principle | | | | | |
| Design Process | A way to express and materialize perspectives through the making of artifacts, alternating between divergent and convergent thinking. | Interview Group 1<br>"I1 (10'21): Okay, ah. This question was weird. So you remember, you mentioned a bit about your project so can you retell, like what was your project about?<br>R1 (10'35): My project was about the class, because the teacher wants the children to learn but sometimes they are just tired and it is boring and they do other things on their Chromebook."<br><br>(level 1) | **Generate ideas** refers to the action of expressing ideas (verbally, visually, tangibly) regarding a prompt or problem framing and understanding the basic elements of a design process. | **Divergent and convergent thinking** refers to the combination of divergent and convergent thinking (Gajda et al., 2017) | **Originality and appropriateness** refers to the importance of the context that permeates what is considered original and what is considered appropriate (Gajda et al., 2017) |

**Table 4**
Template approach and codes used for the principle Decoding.

| Code | Description | Example | Level-1 | Level-2 | Level-3 |
|---|---|---|---|---|---|
| Principle | | | | | |
| Decoding | A way to analyze and reflect upon the manner in which other people and corporations have materialized intentions in technology | Interview Group 2<br>"R1 (08'50): Well, I think it is important because it takes out the. Uhm, in my project the student, without this the student would probably, like now, just go around and ignore what they should do and they do not listen to the teacher because the teacher is off somewhere. Then he comes back and the students, as fast as they can, go in to the thing that they should do and then fool the teacher. And then the student that would want to do the work gets irritated because of the students that do not do it. And then both of the students get lower grades because they could not do what they should do and did not want to do what they should have done."<br><br>(level 1) | **Technology** analysis looks at the material properties of a given artifact in terms of its output, input and the materials used (hardware and software). Inquiries concerning<br><br>+ **Purpose** is related to the question of the intended use of the artifact: what does it invite the user to do and which activities is it meant to support? (Dindler et al., 2020) | **Technology** + **Purpose** + **Use** brings attention to how the artifact is actually used as part of everyday life.<br><br>+ **Value** concerns how a given artifact reflects or foregrounds certain values or interests and promotes particular worldviews and assumptions. (Dindler et al., 2020) | **Technology** + **Purpose** + **Use** + **Value** + **Impact** focuses on the influence that artifact assert on our lives as individuals and as a society. This may be explored through desk research or discussing the historical evolution and implications of technology.<br>+ **Argumentation** looks at the arguments that the producer of the artifact provides for its use.<br><br>(Dindler et al., 2020) |

technologies and their understanding of the societal implications (Table 4). In other words, we evaluated whether the students could grasp how the technology worked and its intended use (level 1), toward an understanding of how the technology is actually used in everyday life (level 2) and their ability to explain the impact of the technologies on individuals and society (level 3).

The codes for the categories "opportunities" and "challenges" were defined inductively. For the category "opportunities", we identified concepts that emerged during the coding process corresponding to students' signs of learning. For the category "challenges", we focused on issues that occurred related to the design of the activity, the facilitation, or technical tool. In this case, the three-code level represented a hierarchy of students' learning signs and of the impact of issues during the learning activity (see example in Table 5).

During the coding process, two researchers performed the analysis blind. After their individual coding, they reached shared agreement on the codebook through five meetings. Definitions and descriptions that resulted for each category and concept were documented in a shared code book. Finally, to complement our analysis, we revised and included the researchers' observation notes on the activities as well as the teachers' feedback gathered in notes during discussion meetings after each intervention session.

### 3.3. Workshop procedure

The overarching theme for the intervention was "The Future Classroom" — a theme that was developed during the co-design process with the teachers and chosen to provide a close context for the students to identify with. We believed this topic would help to scaffold the students' computational empowerment during the learning activities, because the school environment is a large part of students' everyday experiences. The intervention contained five sessions carried out on five separate days over a two-week period. Each of the five sessions consisted of four parts of 45 min each. In this study, we present a detailed procedure only for selected learning activities. The goal is to illustrate how the four core principles *Closeness, Embodied Learning, Design Process* and *Decoding* unfolded in combination in these different learning activities. In the following sections, we focus

**Table 5**
Template approach and codes used for the opportunity "Development of vocabulary".

| Code | Description | Example | Level-1 | Level-2 | Level-3 |
|---|---|---|---|---|---|
| Opportunity | | | | | |
| Development of vocabulary | Language expression of specific terms and words related to ET tech fundamentals and societal implications | Interview Group 1:<br><br>"That machine learning is about recognizing things and predicting, what it could be, and augmented reality is like feature points to make a visualization."<br><br>(level 2) | Use randomly specific terms related to technology and/or societal implications | Use specific terms consciously in relation to technology and/or societal implications | Use specific terms in relation to technology and/or societal implications and make connections outside the activity |

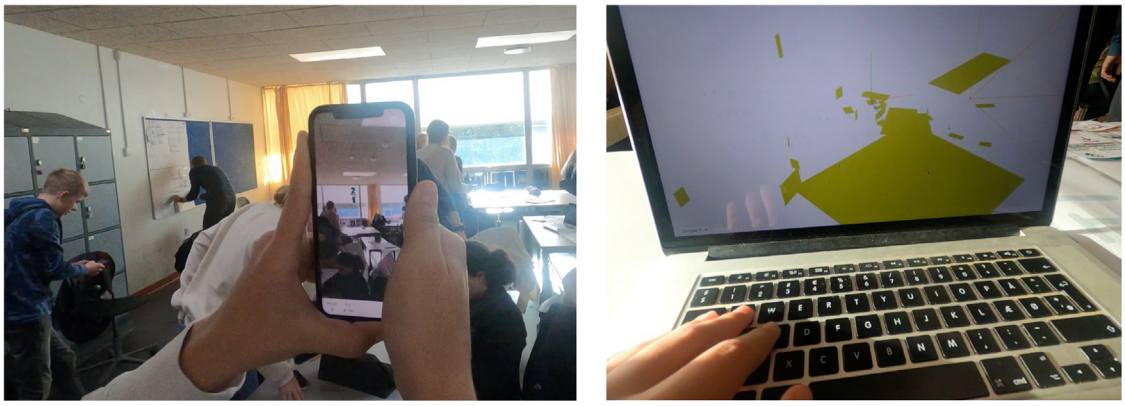


**Fig. 2.** AR application (left); desktop application (right).

on the learning activities (A1) Augmented Classroom; (A2) Data Compass; (A3) Embodied Data Modeling and (A4) Value-Driven Design Activity. First we will describe the procedure, then present our findings of the analysis of each learning activity.

### Activity 1 (A1): The augmented classroom

The purpose of the *Augmented Classroom* activity (A1, Fig. 1) was to teach students about how augmented reality technology collects spatial data about the physical space in order to add virtual content to it (Lunding et al., 2022). To this end, we first introduced the students to basic technological knowledge by explaining real-life examples in social media. The students were then invited to an embodied activity in which they moved around to track the physical space in order to build an AR mathematics game (Fig. 2).

The specific purpose of the game was to collect all the proper fractions in the spatial layout of the classroom as quickly as possible. The students used an AR application in groups and a desktop application to build and play the game. The AR application was used to collect spatial data about their classroom. The desktop application then revealed the model that was created based on the data collected by the AR application, allowing the students to add the virtual fractions to the space. The students had various options to customize their game: they could decide where they wanted to place a fraction, which fraction it was, whether it was proper or not, and how it could be picked up during game play. Finally, the students could use the AR application to play the game they had built by picking up virtual fractions in their physical classroom. The AR mathematics game was designed as a way for the students to experience what a future classroom activity might be like while learning about the fundamentals of AR technology.

### Activity 2 (A2): The data compass

The purpose of the *Data Compass* activity (Fig. 1, A2) was to introduce students to personal data as a concept which describes them as individuals (Bilstrup et al., 2022). At the same time, the activity focused on the value of this data for those who collect it. To this end, a few days before the intervention the students had completed a pop quiz with the theme "Which person from *Paradise Hotel* are you?" *Paradise Hotel* was a popular TV series among the teenagers. In the quiz, the students answered personal questions about themselves, such as *their age, how far they have to walk to school, how their friends would describe them in one word,* etc. During the intervention, we first introduced the students to the questions (1) "What is data?" and (2) "Where is it used?" Then we showed them the dataset we had obtained from their answers to the pop quiz. Second, we designed an analog tool based on a coordinate system (Fig. 3). This consisted of two axes printed on a DIN A3 sheet of paper together with data types (age, favorite subject, etc.) on small snippets of paper which could be glued onto the coordinate system. The horizontal axis described how willing students are to share data, and the vertical axis described how valuable they think it is to the receiver. For example, the students asked themselves and discussed: "How willing am I to share how many hours I use on my smartphone a day?" and "How can those I share it with make use of this information?" For this activity, students were introduced to the *Data Compass* and asked to plot the types of data collected in the pop quiz into the compass at the beginning of the second session so that their plots could be used in classroom discussions about sharing personal data. At the end of the third session, the students repeated the exercise to see how the activities had changed their perspectives on the data.




**Fig. 3.** Example of the Data Compass.

### Activity 3 (A3): Embodied data modeling

The purpose of the *Embodied Data Modeling* activity (Fig. 1, A3) was to support students' sense-making of personal data through bodily engagement (Bilstrup et al., 2022). To this end, the activity consisted of students embodying a two-dimensional K-Nearest Neighbors (KNN) model, acting as data points representing their own personal data. The KNN algorithm is a simple ML algorithm that determines the category of a new data point based on the categories of the surrounding K number of neighbors. For the activity, a coordinate system was drawn on the floor in a large room and the students arranged themselves in the coordinate system according to the axis and simulated the KNN algorithm with a K-value of two, four and six. The students then asked their two, four and six closest classmates questions. An example was to create a model that aimed to predict which sport a student preferred (e.g., dancing, handball or e-sport) by looking at their height and hours of stationary activity each week. The whole class would locate themselves in the coordinate system according to their height and hours of stationary activity, ask their two, four and six nearest neighbors about which sport they prefer, and note if the model was able predict their preferred sport correctly with the different K-values. At the end of the activity, the teacher took a photo of the students' placements from above, as seen in Fig. 4, while the students held colored papers representing their preferred sport (e.g. students who preferred e-sport held a blue-colored paper). The photo was used in the classroom for discussion of how well the model had worked and if we were able to predict output based on our input.

### Activity 4 (A4): Value-driven design activity

The purpose of the *Design* activity (Fig. 1, A4) was to get the students to identify possible value dilemmas related to emerging technologies and to reflect upon possible trade-offs that potential stakeholders might need to consider. To this end, the activity was conducted across four sessions (session 1, 2, 4 and 5; see Fig. 1). In the first session, the students were encouraged to explore their current class context and a more future-oriented class in China (40 min). The Chinese Class Care System uses facial recognition based on artificial intelligence to monitor student performance in class. The students received context mapping cards (Fig. 5) displaying different technologies, actors, benefits and risks, and conflicts of interests. To explore the context, the students needed to be able to identify and describe different technology applications and their purpose, different direct and indirect actors, possible implications for these actors, and conflicts of interests. The students taped the cards onto a large sheet of paper and were encouraged to visualize connections (e.g. conflict of interests between actors) and write arguments on their map. We assumed that through this process students would develop an understanding of different societal values in relation to technology and education, as well as between different actors within each of these culturally specific contexts. In the second session of the intervention (Fig. 1), the purpose of the design activity was to define a design goal based on one of the conflicts of interest they had identified in session 1 and to design ML and/or AR technology to address the conflict of interest in a future Danish class context. The students used a design goal template to document their ideas, on which they had to respond to a series of questions (Fig. 5, right).

In the fourth session of the intervention (Fig. 1, A4), the main purpose of the activity was to enable the students to explore the technology fundamentals by implementing them in their design ideas for the future classroom. Each group revisited the design template with a coach, who helped them make the design goal and the related details in the template more solid. The coach team consisted of both teachers and researchers. This task was motivated by our observations that the students had problems with defining a meaningful design goal in the second session. After the ultimate design goal had been defined, the students began with the ideation, which was divided into five phases:

1. Individual brainstorming (5 min)
2. Sharing ideas with the other students in their group (10 min)
3. Collectively deciding on one idea or merging ideas (10 min)
4. Each group was then paired with another group. The purpose of the task was to present ideas to each other and to give constructive feedback.
5. The individual groups then had 20 min to integrate the feedback and design the final idea. For the ideation phase, the students used a template to document the evolution of their ideas and to explain how the technology would be used (Fig. 6).

Subsequently we introduced the students to a storyboard template and instructed them to visualize one typical day for how their technology design might be used in the classroom. They were also encouraged to illustrate the trade-offs the technology might entail for the stakeholders involved. For this purpose, we handed out pens and large paper sheets (Fig. 7) which the students used to produce the storyboards (40 min). The purpose of the task was twofold. First, we aimed to assess the students' capability to identify the opportunities, tensions and limitations of the impacts of the ML and AR technologies in society. Second, we aimed to investigate how using storyboards opened up a shared space for dialog about different perspectives on ethical and societal implications.

## 4. Results

In our analysis, we focused on how to scaffold computational empowerment in practice using the four principles and how they emerged in each learning activity. Furthermore, we were interested in learning about students' self-perceptions as well as the teachers' feedback on the opportunities and challenges arising in the activities. In this regard, the students reported fewer challenges, and our findings are mainly based on the teachers'



**Fig. 4.** A group of students representing data with their body (left); the same picture taken from above (right).

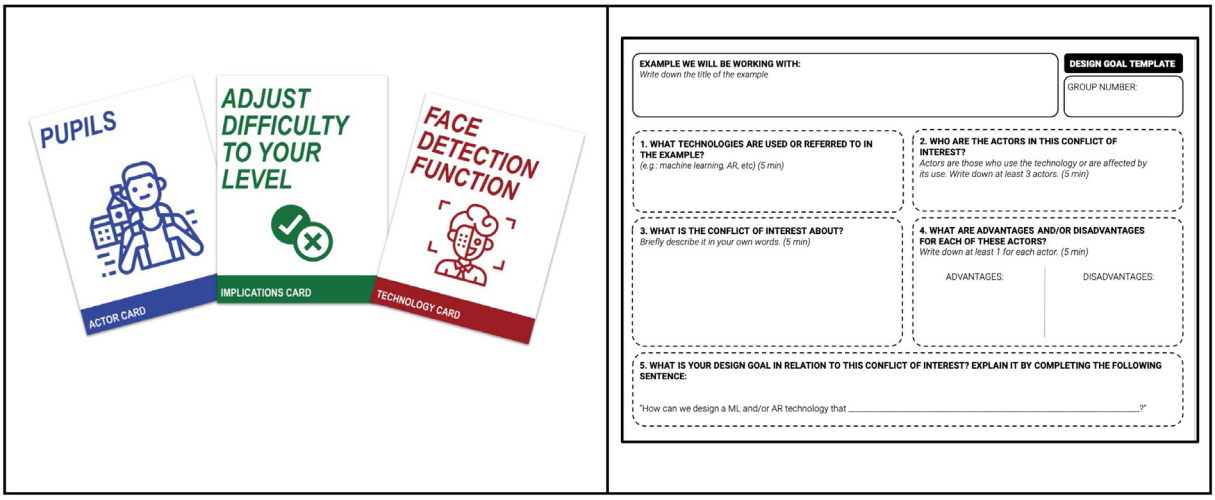



**Fig. 5.** Example of the context mapping cards (left); Example of the design goal template (right).

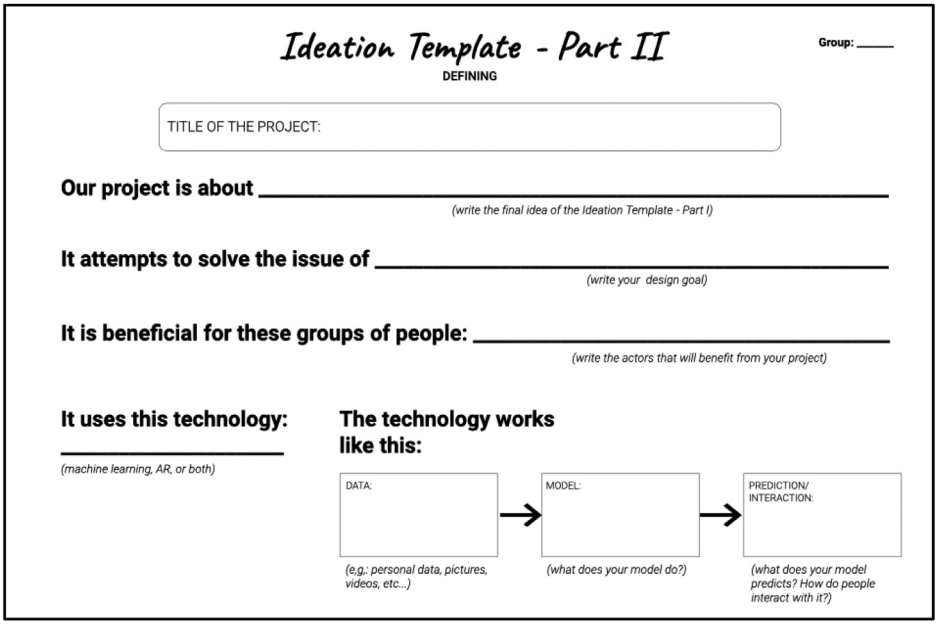



**Fig. 6.** Ideation Template.



**Fig. 7.** The students mapping out the value design cards (left) and presenting their storyboard during the final presentation (right).

feedback. In the following, we present our findings, supported by examples of students' and teachers' comments. We will refer in the descriptions specifically to the 12 themes used in our codebook and named (*1*) *closeness;* (*2*) *embodied learning;* (*3*) *design process;* (*4*) *decoding;* (*5*) *engagement;* (*6*) *vocabulary;* (*7*) *knowledge;* (*8*) *awareness;* (*9*) *misconception;* (*10*) *technical issues;* (*11*) *facilitation issues;* (*12*) *activity design*. Furthermore, we indicate the achievement level in each category in terms of degrees from 1 to 3 (Fig. 8 shows the average values in each category), with 3 being the strongest learning signs (themes 5–9) and indicators of specific issues (themes 10–12) in the category. In relation to the principles, the levels 1 to 3 represented different ways of integrating this aspect into a learning activity (see Section 3.2).

### A1: Learning about spatial data

The students were introduced to the *Augmented Classroom* activity with an explanation of how they were already using AR applications in their everyday lives (closeness: level 2), e.g. Snapchat filters used by teenagers to augment their photos, and how these technologies work with feature points to scan, such as faces, spaces, surfaces. This introduction not only sparked the teenagers' interest, it also highlighted the relevance of AR technologies for them personally. During the AR Classroom activity, the students were asked to scan a room and to catch and place virtual fractions in order to build an AR mathematics game. The students highlighted the AR Classroom activity as the one they liked the most (engagement: level 2 and level 3). One student said: "I think day two was really fun because of the augmented reality app. You had to put the math equations in the middle because you had to scan the room and put them in. Yeah, it was really fun to do. And I felt like I learned a lot because we made our own game". The teachers who participated in the session confirmed this observation. They described the activity as a "nice noise of students who were actively crawling on the floor and laughing".

The collaborative task in the activity mainly promoted spatial interactions (embodied learning: level 2) between the students. This procedure helped the students to develop vocabulary about AR (vocabulary: level 2) such as feature points, data and model. Second, they obtained knowledge about how tracking of physical spaces worked. Third, they expressed reflections about human–societal impacts related to AR technologies. Specifically, one student said: "We walked around with a phone and tracked the room and placed these feature points, which then based on this information could make a model. And if you do it in your home, where you are every day, then it can start to figure out a lot of things about you".

The reported challenges in the activity were related to certain technical limitations in the AR technology whereby the model created did not match how the real world looked. Specifically, the students pointed out that they had a hard time "catching" the virtual fractions because the system did not work well. They therefore experienced the technical limitations of the AR as a fault in the application. Another student explained that he found the application too complicated and it took him a long time to learn how it worked.

Overall, the results made clear that the *Augmented Classroom* activity unfolded the principles *Closeness* and *Embodied Learning*. The combination of these two principles was shown to be useful in supporting the students' engagement in the collaborative task, their exploration of the concepts spatial data and tracking systems of AR technologies, and awareness of the societal impacts of AR technologies in the teenagers' everyday lives. Potential for improvement of the activity can be found in the embodied experience (embodied learning, level 2), which may have been impacted by the technical issues of the prototype.

### A2: Understanding the use of data and their ethical implications

In this exercise, students rated personal data in the *Data Compass,* a coordinate system with two axes. The horizontal axis referred to the students' willingness to share data, and the vertical axis described how valuable they thought it was to the receiver. This procedure in the activity opened up several opportunities for student learning. First, the students realized how valuable their own data was for them (closeness: level 2 and level 3) and how it could be used by others (decoding: level 1). One student explained, "It was the one where you should put the different points in if you would give the data or not because you were thinking about what data could actually be used by companies and which couldn't be used". Second, the activity supported the students' knowledge about how data was used (knowledge, level 2). Third, it deepened their awareness of societal impacts related to data privacy (awareness: level 2). For example, one student explained: "We had a compass about if we wanted to give up the data, and about if it was useful. We did it twice, and the first time we didn't mind so much, and then I think the second time we had learned a bit more about what it means and what they use it for, and then we were less likely to give up our data".

The reported challenges in the activity were related to students' engagement. The teachers discussed whether the introductory topic of the gifted school was close enough to the students:

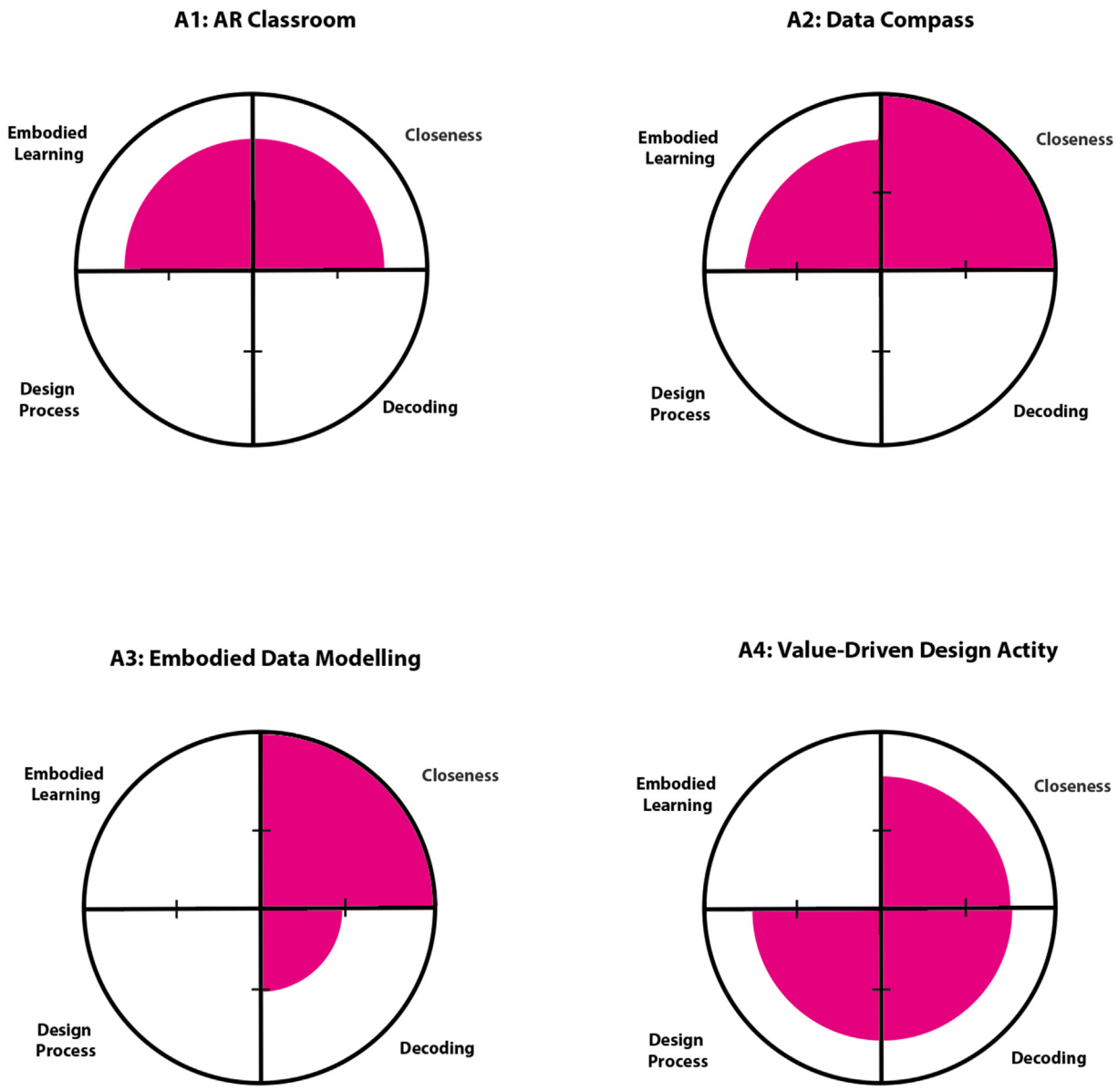



**Fig. 8.** Overview of the results classifying the learning activities into principles Closeness, Embodied Learning, Design Process and Decoding and the average of the results between levels 1 to 3 (see also Section 3.2).

during the activity, the students had seemed a bit disconnected. Some of the students mentioned during the activity that they would not fit into this school.

Overall, the results made clear that the *Data Compass* activity unfolded the principles *Closeness* and *Decoding*. The combination of these two principles was shown to be useful in supporting the students' engagement and their reflections upon the data value for them and the implications of data privacy for the individual. In particular, using both principles allowed the students to understand the relationships between use of the data-driven technologies and the specific impact on themselves. Potential for improvement of the activity can be found in the activity design in relation to students' engagement. The topic of the second exercise may be replaced by themes that are closer to students' everyday experience.

### A3: Enacting and learning about personal data

The students were engaged in the *Embodied Data Modeling* activity through using the data they had provided about their everyday activities, e.g. during their spare time (closeness: level 2). The activity became even more meaningful to them at the moment when this information was linked to their personal data, e.g. age, height, (closeness: level 3). The students' engagement was also supported by the fact that they represented this data themselves with their bodies and rearranged themselves spatially according to different data sets and predictions (embodied learning: level 2). One student explained: "We had to place ourselves in a coordinate system, if you biked to school or walked and stuff like that. Then you had to place yourself based on your level of exercise or if you were a boy or a girl. (...) When you are a part of it, it is more fun than to just look at it". In this regard, the students described the *Embodied Data Modeling* as one of the "entertaining activities" because they were "active and played a role" (engagement: level 1). They also highlighted that the activity "made it clearer how things were connected". They felt highly engaged because they were active themselves and "were doing something and talking about it", rather than someone else telling them what to do (engagement, level 3). The teachers also noticed that the students were curious about

the activity and were enjoying moving around. The procedure of the activity promoted student reflections on what kind of data they would like to share when using ML and AR technologies (awareness: level 1). Furthermore, the activity increased the students' awareness of how technologies make use of their personal data (awareness: level 2). For instance, one student explained the purpose of predictions in ML: "... to categorize people, to find out who in which age group or those who uses the technology a certain amount a day, to create a more accurate group".

The reported challenges in the activity were related to the students' participation in the activity. The teachers noticed that the students hesitated to speak out aloud during the activity. In general, interactions between the students needed a high level of guidance, which limited the discussion about the implications of the use of private data. Furthermore, teachers reported that some of the students had been moving because they actually understood what was happening in the activity, while others had moved without knowing the purpose behind this.

Overall, the results showed that the *Embodied Data Modeling* activity unfolded the principles *Closeness* and *Embodied Learning*. The combination of these two principles was shown to be useful in supporting the students' engagement and motivation to be part of the activity, and it also supported their awareness of the use of personal data by emerging technologies and their personal willingness to share this data. Potential for improvement of the activity can be found in the activity design of the embodied experience (embodied learning, level 2) in order to promote meaningful social interactions between the teenagers. This could help to improve overall student engagement while stimulating collaborative reflection about private data issues.

### A4: Learning about real-world dilemmas of emerging technologies

The *Value-Driven Design Activity* was carried out across four sessions. We framed it in a general context for the intervention of the "future classroom". We assumed that this topic would spark the teenagers' interest in the activity (closeness: level 1). Furthermore, in the actor mapping activity, we introduced dilemmas that were related to the teenagers' concerns (closeness: level 2), e.g. proposals for technologies that could monitor students in the class. The students became engaged in the activity because the design process allowed them "to do something themselves" (engagement: level 1). Furthermore, they enjoyed the dynamics of the pitch presentation (engagement: level 3). One student highlighted the final pitch presentation of their project as a key moment in the design process: "Well, it was really difficult, it felt like you were actually in the middle of selling something (...) I loved that, (...) We just had to pour out answers that we didn't have thought about before, so it was also eye-opening and really interesting".

During the activity, the students were able to generate ideas for their group projects and understand the basic procedure of a design process (design process: level 1). Most students proposed ideas that favored the teacher's control over the students' learning process, e.g. an app for the Chromebook or for Google-Meet that would detect when students are unfocused, bored or tired. Another example was a proposal for translation apps that would help students to be more motivated to learn a language. The *Value-Driven Design Activity* supported teenagers' learning in several respects. First, it helped the students to analyze both the basic properties of ML and AR technologies and their intended use (decoding: level 1). This ability was useful for them when explaining which technologies they used in their design proposals (knowledge, level 1) and also when using specific vocabulary related to data and models (vocabulary, level 1). Second, the students showed their ability for divergent and convergent thinking (design process: level 2) in the design process of emerging technologies. For instance, one student described the brainstorming of their project idea: "In the beginning we thought about using augmented reality to scan their face and to see if you were dreaming or if you were doing your homework, but we didn't like the idea of getting your face scanned. So we thought that we would do it in another way instead". This example also highlights how the students reflected upon the impact of emerging technologies during the design activity (awareness: level 3). In addition, several students' comments showed that they were able to detect contrasting values of different actors in the design and use of emerging technologies (decoding: level 2). For instance, one student explained: "Our idea was to make the Chromebook more efficient, in order to stop students gaming. (...) Then we have two conflicts of interest. The conflict of interest is that the students don't want to be watched on their face or their screens, but the teachers need to know what the students are doing". Also, the pitch presentations when they were discussing each other's ideas helped to deepen their reflections on the societal impacts of emerging technologies (awareness, level 2). For instance, one student described another group's idea: "It was about that the teachers could pop up on your screen when you weren't doing your work and just say 'go back to your work.' That was really scary and horrifying!"

Reported challenges related to the facilitation of the *Value-Driven Design Activity*, e.g. the students mentioned that the instructions were sometimes not clear and that they were short of time (facilitation: level 2). Also, the teachers stressed that the *Value-Driven Design Activity* could be very demanding for the students and they might need additional guidance to complete the tasks. Particularly, the students struggled in the exercise where they had to map the different actors involved in the technology design. They also reported some misconceptions about the activity. One student, e.g., did not understand the relation between the storyboard activity and designing the technology (misconception: level 3). Finally, the students also expressed their hesitation about criticizing their peers during the pitch presentation because they "felt it was rude".

Overall, the results showed that the *Value-Driven Design Activity* unfolded the principles *Closeness*, *Decoding* and *Design Process*. The combination of these three principles was shown to be useful in supporting student interest in the activity, in generating design ideas that included basic properties of both ML and AR technologies, and in generating reflections on conflicts of interest between different actors in the use and design of emerging technologies, as well as on student awareness of the societal impacts of emerging technologies used in a school context. Potential for improvement of the activity can be found both in the design and facilitation of the activity. Specifically, the actor mapping exercise could be simplified and supported by examples of dilemmas that teenagers find easy to understand and are close to their everyday experiences.

## 5. Discussion

We have presented how the principles *Closeness, Embodied Learning, Design Process and Decoding* unfolded in four learning activities aimed at scaffolding computational empowerment in practice. Through unpacking how these principles emerged in each activity, we observed opportunities and challenges for integrating this concept in a formal educational context. Our findings showed that using the principles *Closeness* and *Embodied Learning* jointly in a learning activity increased student engagement and motivation, e.g. in the *Augmented Classroom* and *Embodied Data Modeling* activities. Furthermore, *Decoding* and *Design Process* were the key principles for promoting student awareness

**Table 6**
Learning strategies using the four principles closeness, embodied learning, design process and decoding to scaffold computational empowerment in practice (*highlights future directions).

| *Principles* | Closeness | Embodied Learning | Design Process | Decoding |
|---|---|---|---|---|
| *Description* | *Sparking the students' interests by exposing them to familiar concepts and topics that relate to their own world.* | *Supporting the students' meaning-making from active experiences that require both physical and mental actions* | *Expressing and materializing perspectives through the making of artifacts, alternating between divergent and convergent thinking.* | *Analyzing and reflecting upon the manner in which other people and corporations have materialized intentions in technology.* |
| *Learning goals* | *Strategies based on each principle to support the learning goals* | | | |
| A1: Learning about spatial data | Through the Introduction of examples in everyday use of emerging technologies | Through the promotion of spatial interaction between the students | – | – |
| A2: Understanding the use of data and their ethical implications | Through supporting the students' reflections on how valuable their data is for themselves | **Through promoting meaningful social interactions between the students to increase their capacity for perspective-taking and empathy* | **Through providing a safer space for creating and exploring ethical values without judgment* | Through supporting the students' reflections upon how their data could be used by others<br><br>**Through supporting the students' development on specific terms that are related to societal implications of technologies* |
| A3: Enacting and learning about personal data | Through using data that the students provide about themselves and linking the activity to the students' own personal data | Through encouraging the students to (1) represent their own data with their bodies; (2) **r**earrange themselves in space according to changed data inputs and outputs | – | – |
| A4: Learning about real-world dilemmas of emerging technologies | Through using familiar context related to emerging technologies and exposing them to dilemmas that relate to student's everyday life<br><br>**Through introducing cultural prompts in order to spark reflections on wicked problems and social dilemmas around emerging technologies* | – | Through supporting (1) the students' creation of ideas for their group projects; (2) understanding of the basic procedure of a design process; (3) Ability of divergent and convergent thinking | Through scaffolding the students' (1) analysis of the basic properties of emerging technologies and their intended use; (2) identification of contrasting values of different actors in the design and use of these technologies |

of the societal impacts of emerging technologies. In particular, the combination of both these principles in the *Value-Driven Design Activity* was shown to spark student reflections on the contrasting values of different actors and on ethical considerations in the design of emerging technologies. Based on our findings and potential learning strategies for future work, we propose a framework promoting student empowerment for creating alternative approaches for a digitalized society at large (Table 1). Our framework embraces computational empowerment in practice and highlights the importance of going beyond learning about just the technological aspects of technologies. Specifically, it focuses on moving beyond the dominant technology-driven and individual-centered narratives in technology education, and on supporting student skills in analyzing, creating and rethinking their own digital futures. In what follows, we discuss each principle in detail and outline possible future directions for addressing the challenges identified. An overview of the strategies that emerged from our research for learning about different aspects of emerging technologies can be found in Table 6.

### *5.1. Closeness: Engaging students through themes of personal data and familiar contexts*

A large body of research has discussed the relevance of framing learning contents around themes that are familiar to students (E. Mazzone et al., 2008; Fitton & Bell, 2014; Horton et al., 2012; Malinverni et al., 2021; Toth et al., 2012). For instance, Rogoff (1998) highlighted that the boundaries between the known and the unknown can be crucial in engaging students in learning activities. Iversen et al. (2013) introduced a theoretical account of teenagers' hierarchy of motives, based on studies in developmental psychology. Specifically, the authors distinguished between "meaningful motives" and "dominant motives". Meaningful motives refer to themes that connect with teenagers' interests and preferences and shape their engagement in a particular task; dominant motives refer to activities that are central and important in teenagers' lives. In our research, we explored the principle of *Closeness* as a way of sparking the students' interest by exposing them to familiar concepts and topics associated with their own world. Our findings pointed to student engagement in all four activities, although at different levels. For instance, in the *Value-Driven Design Activity* the students were introduced to the overarching theme of the future classroom. Since they spend a large proportion of their everyday lives in school, this was a topic they could easily relate to personal experiences (level 1). Our outcomes showed that learning contents became meaningful to the students (level 2) when linked to their particular interests and preferences, e.g. the everyday use of emerging technologies or dilemmas they are personally confronted with. Finally, the themes became a dominant motive (level 3) when they stimulated reflections on the impact of emerging technologies in the students' personal lives, e.g. when the activity was linked to the value of their personal data for themselves and others. Despite these promising findings, we believe there is still a need to go

beyond the dominant narratives around emerging technologies by focusing on data privacy and other such themes that support teenagers in their learning processes about these technologies. One possible direction for including the principle *Closeness* within a broader viewpoint could be to introduce the learning activities with cultural prompts. In this regard, Anwar and Bascou (2019) note the benefits of uncovering "efficient methods for capitalizing on student cultural propensities" in the context of learning about intelligent technologies. One example of this approach can be found in Schaper et al. (2020) who proposed learning activities that built on the traditions of students' cultural contexts. They show how this approach helped to spark reflections on so-called wicked problems and social dilemmas associated with emerging technologies, such as fairness and ethical bias.

### 5.2. Embodied learning: enacting data and exploring with the body

Previous research has highlighted that learning activities involving embodied exploration can enhance student understanding of abstract concepts (Malinverni & Pares, 2014), topics requiring emotional engagement (Sakr et al., 2016), and critical thinking (Rowan et al., 2016). In our research, we explored the principle *Embodied Learning* as a way of helping students to make meaning from active experiences requiring both physical and mental actions. Our results highlighted that this principle did motivate the students, both in the *AR Classroom* and *Embodied Data Modeling*, to engage in a collaborative task because they felt active and were performing a movement-based exercise. In addition, in the *Embodied Data Modeling* activity the students represented their own data with their bodies (Mora-Guiard & Pares, 2014; Tscholl et al., 2013). The embodiment of data seemed to support their awareness of how ML technologies make use of their personal data (level 2). However, our findings also showed that the students' engagement in both these activities was mainly through spatial interaction (Hornecker, 2010); opportunities were missed to support meaningful social interactions between the students that could potentially lead to their comprehension of abstract concepts related to emerging technologies. Previous research suggests that meaningful social interactions between students could increase their capacity for perspective-taking and empathy (Antle et al., 2013; Lyons et al., 2012; Roberts et al., 2014; Schaper et al., 2017, 2018). For instance, in the *Embodied Data Modeling* activity, meaningful social interactions can be generated by dynamics involving collective student reasoning about data, but also by collaboration in shared tasks. This procedure could expand student understandings of the fine nuances of how emerging technologies impact our society in concrete ways, because students can compare ethical issues from different perspectives and reach insights about others' points of view.

### 5.3. Design process: express and materialize alternatives for emerging technologies

Design-oriented learning that considers students as builders of knowledge has been shown to be a useful pedagogical strategy for teaching about emerging technologies in K–12 education (Sanusi & Oyelere, 2020; Vartiainen, 2014). This approach is based on Papert's (1980) vision of a world in which children design and program artifacts as a means to create "computational objects to think with". In this regard, Gajda et al. (2017) stress the capability of combining divergent and convergent thinking as one of the core learning goals in the design process. Furthermore, Dindler et al. (2020) point to the need for a digital design literacy that implies students developing abilities to work with complex problems and to argue for the choices in their design process. In our research, we explored the principle of *Design Process* as a way of expressing and materializing perspectives through the making of artifacts, alternating between divergent and convergent thinking. Our results indicate that the students were able to generate ideas for their group projects and to understand the basic procedure of a design process (level 1). Furthermore, they showed the ability to combine divergent and convergent thinking (level 2) when they reflected upon the possible societal impacts their design proposal might entail. However, the students' proposals were not very original and did not represent future visions or alternative approaches for emerging technologies. Rather, their ideas stayed very close to the examples that we had shown them in the intervention sessions. These findings therefore point to the need for novel approaches to engaging students in critical design of, and reflection about, emerging technologies (Iivari et al., 2021). One possible direction for supporting students' future visions of emerging technologies could be to use design fiction as a way of safely exploring ethical and societal implications of technology. Previous research has pointed out that if well-known contexts are useful for introducing teenagers to technologies, then design fiction is useful for expanding and exploring risky ideas about them (Vermeule, 2010). In this regard, Dasgupta and Hill (2020) introduce the design principle "create sandbox for dangerous ideas". This idea is relevant to design processes that involve real-world ethical dilemmas regarding technology, where there is a risk of students assuming that there is a "correct" answer or a predefined solution expected by the teacher. If the dilemma is presented in a design fiction approach, a safer space is created in which students can explore ethical values without judgment.

### 5.4. Decoding: Analyzing technological aspects and societal impacts of emerging technologies

Dindler et al. (2020) present a conceptual model of *Decoding* which describes the activities involved in analyzing and reflecting upon technology artifacts in order to understand their qualities and significance. DiPaola et al. (2020) apply this concept to engage students in stakeholder analysis and to apply ethical design tools with a view to redesigning a social media platform. In our research, we used *Decoding* as a way of analyzing and reflecting on how others, and corporations, have materialized intentions in technology. Our findings show that, during the *Data Compass* and *Value-Driven Design activities,* the students were able to analyze the basic properties of emerging technologies and their intended use (level 1). Furthermore, in the actor mapping during the *Value-Driven Design Activity,* the students identified contrasting values of different actors in the design and use of emerging technologies. However, in none of the activities were the students able to grasp and explain the ethical and societal implications of emerging technologies in general. These findings resonate with the need to strengthen children's and young people's self-cultivation in digital making in the classroom (Schelhowe, 2013) and to provide them with the tools to analyze and critically reflect on the use and impact of emerging technologies. A possible direction for increasing student understanding of the societal impacts of emerging technologies could be to support their development and use not only with technical vocabulary but also with specific terms related to the societal implications of technologies (e.g. accountability, ethical bias, explainability, etc.). For instance, Bilstrup et al. (2020) developed a card-based design workshop that allowed students to reflect on ethical dilemmas by designing their own ML applications. Our study showed that card-based activities could help the students to expand their discussions and reflections on ethical dilemmas and on actors' values in different scenarios.

Based on our findings from this research intervention, it is evident that several challenges still require to be addressed in the

implementation of computational empowerment in practice. Our framework will provide the CCI community with initial starting points for exploring novel strategies for these challenges. We invite the CCI community to take part of this trajectory and explore sustainable strategies (Smith & Iversen, 2018) to employ computational empowerment in practice.

## 6. Conclusions

In this article, we focused on four core principles for learning activities in technology education, namely *Closeness, Embodied Learning, Design Process* and *Decoding*. The aim of the article was to demonstrate how these principles can scaffold computational empowerment in K–12 education. Our findings from a study with 26 students (14–15y) and 9 teachers at a public primary school in Aarhus, Denmark, showed that computational empowerment builds on several different layers, which are these four principles. Specifically, merging the principles *Closeness* and *Embodied Learning* can increase student engagement and motivation in the activities. In addition, *Decoding* and *Design Process* are key principles for promoting student awareness of the societal impact of emerging technologies. The principle of *Decoding* can support students in analyzing and critically reflecting on the use and impact of emerging technologies. Building on this knowledge, the principle of *Design Process* enables students to create alternative approaches for these technologies. In future work, we will revisit this approach and expand our framework in the context of multiple research interventions.

## Selection and participation

32 pioneer teachers and 2 special consultants from Aarhus municipality, Denmark, worked as our main research partners for the duration of the CEED project. Specifically, 9 pioneer teachers were closely involved in this research intervention, which aimed to explore teaching practices for emerging technologies in K–9 education. The pioneer teachers were considered 'pioneers' because they had received in-service training in digital fabrication and design processes and had integrated aspects of this training in their teaching practice for between one and six years. All of them belong to a local network in Aarhus and can spend one day per week on further developing their expertise in this area. As members of this network, they furthermore act as ambassadors in their schools by coordinating design and technology projects and supporting fellow teachers. The 32 teachers who belong to his network received an open invitation to participate in the project, and 9 teachers responded positively. Three teachers (f = 1, m = 2) eventually formed a 'core group' who collaborated more intensively with the researchers. The teachers decided for themselves who would become part of the core group, based on available time and interest. In this intervention, 26 students (f = 13, m = 13) aged between 14 and 15 years from a public primary school in Aarhus, Denmark, participated. The students were from the same school class and were selected by one of the core pioneer teachers. The responsible teacher sent the project information and the informed consent to legal tutors. In the consent forms we asked both the legal tutors and the students for their agreement on data collection and dissemination. The parents were also invited to contact our research team for further information.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

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