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Co-designing sustainable practices for emerging technologies education

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Abstract
The paper addresses the current lack of emerging technology education in both research and practice and the urgent need for preparing future generations for a digital future. Based on a two-year participatory design process with Danish researchers and pioneer teachers, the article presents outcomes on the collaborative development of interdisciplinary teaching and learning practices for K-12 education, and the professional development that the process spurred within the teachers' community. The findings indicate that the participatory process became a catalyst for the development of meaningful teaching activities, a community of practice, and the shaping of a common future educational agenda. Furthermore, the results showed how the approach supported teachers' transformation from active co-designers into change agents for future emerging technology education. Based on an exemplary case, the article demonstrates how participatory design with teachers can support the development of new sustainable practices and communities for emerging technology in education.

Keywords Computational empowerment · Participatory design · Emerging technology education · Teachers · K-12 education

Introduction

Participatory Design (PD) is a polyvoiced perspective embracing complex and often blurred constellations of users, contexts and purposes (Halskov & Hansen, 2015). It is an approach that allows stakeholders a voice in the design process as decision-makers through collaboration, mutual learning, and empowerment (Frauenberger et al., 2015; Kensing & Blomberg, 1998; Simonsen & Robertson, 2013). PD has contributed to the development and implementation of technology in many contexts and sectors. However, only recently scholars have also started to apply PD in educational settings (Tuhkala, 2021) as a means to involve key stakeholders (e.g. teachers, students, policy-makers) in the development of educational practices.

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Emerging technology is a growing field in K-12 education (Van Mechelen et al., 2022). Yet only a few researchers have employed PD as an approach to identify opportunities to integrate themes around emerging technologies into the school curriculum (Lin & Van Brummelen, 2021; Tamashiro et al., 2021; Touretzky et al., 2019). Other researchers (Dindler et al., 2020; Iivari et al., 2022; Kafai et al., 2020; Tissenbaum et al., 2021) and policy-makers (Caspersen et al., 2022; Vincent-lancrin & Van der Vlies, 2020) have provided recommendations about how to introduce emerging technologies into education that go beyond concepts of computational thinking and include social, ethical and societal aspects, through e.g. Computational Empowerment (Dindler et al., 2020) purely. At the same time, scholars in Human Computer Interaction call for explainable, transparent, ethical aspects of technological innovations (Abdul et al., 2018; Akata et al., 2020) and that users need to understand the inner workings of emerging technologies and impact of everyday life. However, considering the novelty, complexity, and teachers' unfamiliarity with those types of technologies, there is still a gap in literature about how to bridge research and practice with the goal of creating long-lasting and sustainable impact in emerging technologies education (Van Mechelen et al., 2022). In this regard, Van Mechelen et al. (2022) proposed a future research agenda which foresees, among others, the active engagement of teachers in the development of learning activities and tools in school environments. The same authors also call for strategies and practices that promote mutual learning processes and support teachers in integrating human-centred and participatory design approaches in existing and new school curricula.

We present in this article PD as a way to explore and transform 'what and how' needs to be taught about emerging technologies into educational practices for the classroom. Specifically, we investigated how PD can contribute to address four core challenges in emerging technology education. First, since the subject as such still does not exist in many countries, teachers have little experience with the technologies themselves and they do not know which themes should be taught. Second, the characteristics of emerging technologies are highly complex and their future impact for people and societies is uncertain (Boon & Moors, 2008; Millea et al., 2005; Rotolo et al., 2015). Their complex nature and characteristics make them abstract and difficult to teach, especially to non-experts such as children and young people. Hence, the educational community needs to develop teaching practices for an interdisciplinary subject integrating computer-, technical- and social science into K-12 education. Third, the subject demands the exploration of new ways of teaching and strategies on how to engage students in learning about emerging technologies in formal learning contexts. Thus, a vast challenge remains to develop appropriate learning activities and tools that support students in critically reflecting on the characteristics of these technologies and their ethical and societal impact (Schaper et al., 2022). Fourth, there is a need for strategies to scaffold teachers' long-term engagement that lead to sustainable communities of practice (Smith & Iversen, 2018) in emerging technology education.

To address these challenges, PD has shown to provide opportunities for mutual learning processes in education with practice communities (Dindler et al., 2020). Our approach engages teachers as protagonists (Iivari & Kinnula, 2018; Iversen et al., 2017) in the design process of co-designing didactics and learning activities about technical, ethical and societal aspects of emerging technologies. The protagonist approach provides people a voice in design processes and empowers them 'to shape technological development and critically reflect on the role of technology in their practices' (Iversen et al., 2017). The research project Computational Empowerment for Emerging Technologies in Education (CEED) involved a group of 11 researchers across social and technical faculties at Aarhus University, as well as a group of 11 pioneer teachers with some or little experience in teaching

digital technology in K-9 from Aarhus Municipality, Denmark. These teachers were part of a municipality organisation who spent one day a week exploring and experimenting with learning practices around digital technology in education. Our approach to emerging technology education is framed by the concept of C*omputational Empowerment* as a concern for how children are empowered to make critical and informed decisions about the role of technology in their lives (Iversen et al., 2019). Computational Empowerment shifts focus from programming skills towards providing children and young people with the means necessary to take part in technological development. Such ideas are strongly linked to the Scandinavian tradition of PD, that emphasises democracy, agency and empowerment (Simonsen & Robertson, 2013). Together with the teachers, we aimed to explore, co-design and iterate on exemplary learning activities and possible sustainable agendas for emerging technologies in education (Dindler et al., 2020). We focus on an exemplary part of a larger PD process in order to demonstrate how to explore and develop models for emerging technology education that build on existing practice.

More particularly, we aim to address the following research questions:

- RQ1: How can we explore and develop engaging and interdisciplinary teaching practices for future emerging technologies education?
- RQ2: How can long-term engagement with teachers lead to sustainable communities of practice of teaching emerging technologies?

This article is structured as follows. First, we give an overview of PD practices in education and discuss recent tendencies in PD research on issues of emerging technology education. Subsequently, follows a presentation of the research methods and findings resulting from a longitudinal PD process with 11 primary school teachers from Aarhus Municipality in Denmark. Finally, we discuss the results in light of our PD approach aimed at developing protagonist communities and supporting sustainable social change in emerging technology education.

Participatory design for technology education

In technology education, teachers' participation has ranged from designing learning practices and curricula to the development of strategies to empower educational communities (Tuhkala, 2021). In this regard, PD research has focused on teachers' expertise in education. However, despite being a growing field, only little research has been done that involves teachers in PD research related to emerging technology education. In a recent systematic review on this topic, van Mechelen et al. (2022) highlighted how teachers are either actively involved in the preparation of learning activities (Klopfer & Sheldon, 2010; Mouta et al., 2019; Sabuncuoglu, 2020; Toivonen et al., 2020) or the facilitation of those in formal and non-formal settings (Bressler & Mohnke, 2015; Estevez et al., 2019; Gong et al., 2018). The same authors observed that only in a few studies, teachers participated in both the backstage work to prepare a research intervention and the facilitation of exemplary learning activities. For example, Charlton and Avramides (2016) actively involved teachers in constructing knowledge and experimenting with ideas on how an IoT system could be used for collaborative, problem-based, and multidisciplinary STEM education. Heinze et al. (2010) reported on a three-year-long collaboration between an AI researcher and two local teachers to develop a

K–6 AI curriculum as part of the Scientists-in-Schools program in Australia. The learning objectives, content, and activities were developed collaboratively and tried out by the teachers across subjects and in multiple iterations. In this context, Nicholson et al. (2022) highlighted the benefits for both the teacher and the researcher of engaging in co-teaching in the classroom. In addition, (Woolner et al., 2007) stressed the importance of including teachers' unique and contrasting perspectives when working in a PD process with diverse stakeholders (designers, architects, teachers) in a school environment.

Van Mechelen et al. (2022) suggested as a future agenda in emerging technology education that teachers should be actively engaged in both backstage work and facilitation, and coordinate professional development programmes. At the same time, this process requires a careful integration of learning activities in formal school environments and develops cross-curricular approaches beyond STEM subjects. In this regard, since many studies tend to focus on one-time projects or interventions, Tuhkala (2021) and van Mechelen et al. (2022) stress the need for more longitudinal research about PD with teachers which can lead to more nuanced findings about the development and use of learning activities and tools in different educational settings, and how they support students' learning about emerging technologies (van Mechelen et al., 2022). This resonates with recent developments in PD, that argue for the need for long-term and large-scale perspectives on digital thinking, design and democracy which embraces the engagement of multiple political and organisational levels, and the value of direct participation with existing practices of teachers and students in the PD process (Bødker & Kyng, 2018; Smith et al., 2020).

Research case

The research project CEED is aimed at exploring and building new practices of Computational Empowerment for emerging technologies in Danish secondary education through a cross-disciplinary approach between computer science, humanities, and engineering. The overall objective for the research project is to explore and develop new ways of teaching K-12 students about technologies such as Machine Learning (ML) and Augmented Reality (AR), with a particular focus on Computational Empowerment. This has been done through a participatory and interdisciplinary approach, integrating technical and humanistic aspects into the teaching practices, through a mutual learning process between researchers and teachers. This approach allowed the ongoing engagement of key stakeholders in situated learning environments and was able to include diverse voices and perspectives in the development of future learning practices, tools and activities (Smith & Iversen, 2018).

In the reported research, we have taken teachers' existing teaching practices as a point of departure, and provided teachers with a leading role in shaping and co-designing new agendas for emerging technology education. We build on these practices to research and develop the field of emerging technologies through a continuous process of collaboration with a selected group of teachers. In this article, we describe and analyse how we took the point of departure in existing educational practices and provided teachers with a mutual and leading role in shaping sustainable agendas for emerging technology in, and as part of, their own professional practice. In the following section, we will describe learning goals for the activity design, the methodology of our co-design process with the teachers, the procedure of workshops in which data was collected and how it was analysed.

Co-designing emerging technology education with teachers

In the following, we provide information about the participants, describe the different phases of the PD process with teachers, and explain the methods for qualitative data collection and analysis.

Participants

A total of 11 teachers with different disciplinary backgrounds participated in the process. These teachers, of which 7 men and 4 women, teach a diverse range of subjects in different schools in Aarhus Municipality (see Table 1). They are considered 'pioneer' teachers because they have received in-service training in digital fabrication and design processes, and have integrated aspects of this training in their teaching practice for up to one-six years. As part of a local municipality network, they spend one day a week developing their expertise in digital technology education, and act as ambassadors in their schools by coordinating design and technology projects and supporting fellow teachers across the school network. Through the network owners and coordinator agreed with the researchers to openly invite the 'Wednesday Team' consisting of 11 teachers for a kick-off workshop, and from here see who was interested in engaging in the full process. On average, nine to ten of these teachers participated in the main workshop sessions, with four teachers eventually forming a 'core group' who collaborated more intensively with the research team in developing and carrying out the classroom interventions. The teachers decided who would become part of the core group based on their available time and interest. In addition to the teachers, two special consultants from Aarhus Municipality participated in the kick-off and in two of the main sessions in the process. As special consultants, they were responsible for the local network of pioneer teachers and all technology education initiatives on a municipal level (see Table 1).

The project team, in turn, consisted of 11 academic researchers with backgrounds in computer science, social sciences and humanities, interaction design and engineering (see Table 1). Seven of these researchers had a leading role in preparing and facilitating the PD sessions, whereas the in-classroom interventions were then conducted by a smaller team of four researchers.

Learning goals for activity design

The purpose of this PD study was to explore how we could support the development of students' Computational Empowerment in their design-oriented engagement with emerging technologies and their implications. Therefore, we focused on teaching in parallel about technology fundamentals (e.g. the functioning of computational models) and related ethical and societal implications (e.g. data privacy, security, fairness, etc.). At the same time, we aimed at integrated this focus in a design activity that was carried out across the teaching activities. We decided to focus on technologies based on Machine Learning (ML) and/or Augmented Reality (AR) because they represented generalizable technology fundamentals and implications for emerging technologies (Fig. 1). The learning activities were framed to engage the students critically and curiously with the construction and deconstruction of emerging technologies. Further, we aimed at

Table 1 An overview of participating teachers, municipality representatives and researchers

Teacher	Gender	Teaching subjects and grades	Researcher	Gender	Disciplinary background
T01 (core)	Male	Mathematics, religion	R01 (core)	Female	Social sciences and humanities
T02 (core)	Female	Danish, English, home economics, natural science	R02 (core)	Male	Social sciences and humanities
T03 (core)	Male	Mathematics, physics, sports, chemistry	R03 (core)	Female	Interaction design
T04 (core)	Female	Mathematics, physics	R04 (core)	Female	Interaction design
T05	Male	Mathematics	R05 (core)	Male	Computer science
T06	Male	Special school education	R06 (core)	Male	Computer science
T07	Female	Danish	R07 (core)	Female	Computer science
T08	Female	Mathematics, physics	R08	Male	Interaction design
T09	Male	Mathematics, biology	R09	Male	Engineering
T10	Male	Mathematics, physics, chemistry	R10	Female	Computer science
T11	Male	Biology, geography	R11	Male	Computer science
Municipality	Gender	Role and responsibility			
M01	Female	Special consultant technology education			
M02	Male	Special consultant technology education			

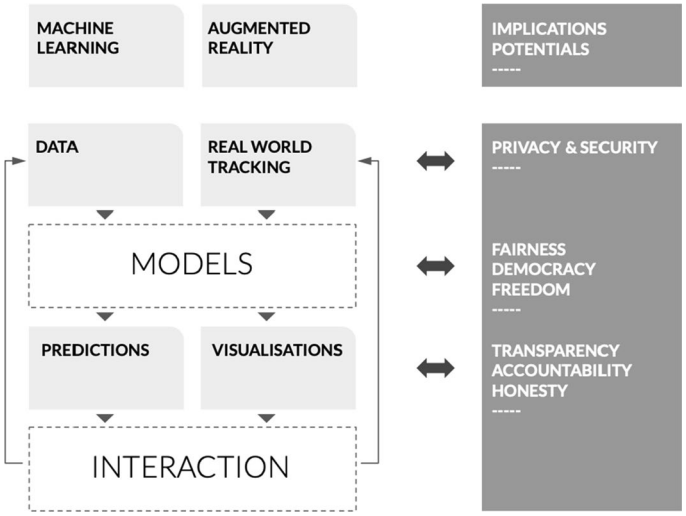

Fig. 1 Technology fundamentals of technologies based on Machine Learning and Augmented Reality and an overview of related social implications

scaffolding students' skills and knowledge to redesign technologies that are attuned to visions for sustainable global futures.

Participatory design process with pioneer teachers

The overall aim of the PD process with teachers and representatives of Aarhus Municipality is to outline an intervention study focused on introducing middle school students to ML and AR. Since emerging technology is a complex subject and difficult to teach, we needed to find ways to support teachers' engagement and motivation throughout the project, to leverage their interdisciplinary expertise in teaching and to integrate teachers' perspectives in the research agenda. To do so, we built on previous long-term engagement with local communities of teachers in technology education (Smith & Iversen, 2018), introducing a holistic approach to PD as a sustainable practice of social change. This approach consists of three dimensions of engagement: *Scoping*, *Developing*, *Scaling*, with heterogeneous communities and larger ecologies of social and technological transformation. In this study, we included an intermediate phase 'Intervening' which describes the exploration of educational activities in practice. Hence, the co-design trajectory can be divided into 4 phases including a total of seven workshops and five intervention or *teaching* sessions, as depicted in Fig. 2. The four phases are (1) scoping, (2) developing, (3) intervening, and (4) scaling, and will be explained in further detail below.

The aim of *Phase 1: Scoping*, was to create a space for mutual learning which allows diverse stakeholders to explore, rehearse and develop future visions together and build a community of practice (Smith & Iversen, 2018). Here, we introduced the participants to emerging technologies and familiarised them with the concept of Computational Empowerment, as well as setting the agenda for the upcoming sessions and process. Two sessions were organised in this phase: (1) a pre-meeting (1,5 h) to build rapport with the participants and set expectations, and (2) a kick-off meeting (4 h) to officially launch the project and generate some initial ideas for the upcoming intervention (Fig. 3, Phase 3). Both

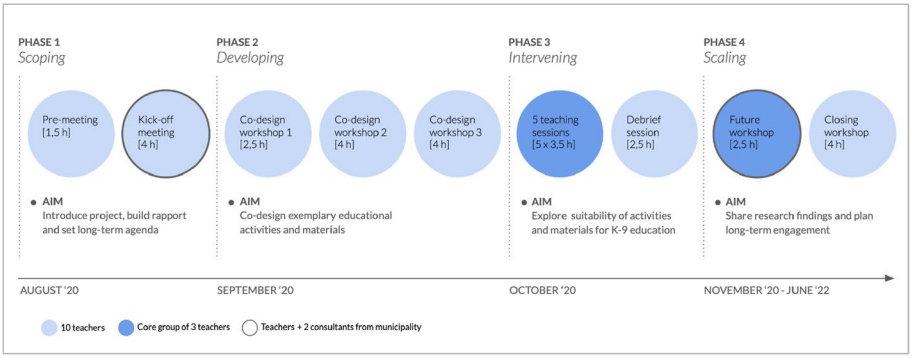

Fig. 2 Overview of the different phases of the PD approach presented in this article. The process is an exemplary part of a larger series of experiments within the project

Fig. 3 Teachers exploring hands-on activities during the kick-off meeting

sessions included a combination of plenary presentations (e.g. about the project aims and notion of Computational Empowerment) and hands-on activities in small break-out groups (e.g. interacting with AR and ML demos and generating ideas). Eight researchers and 10 teachers participated in both sessions. During the second session, the kick-off meeting, two special consultants responsible for technology education on a municipal level participated as well. The outcomes of the first phase were mainly intangible including the understanding of diverse range of backgrounds and perspectives of the participants and a common language. Tangible outcomes included a shared agenda and initial ideas for learning activities about AR and ML presented as posters and video recorded.

The aim *Phase 2: Developing* focused on the generation of tangible and intangible outcomes that could support users' critical reflections upon technologies and their societal impact (Smith & Iversen, 2018). In this project, we explored and co-designed educational activities and tools with teachers based on learning principles derived from the notion of Computational Empowerment. Three sessions were organised in this phase: (1) a co-design workshop (2,5 h) to finalise the agenda and build further on the ideas of the first phase, (2) a second co-design workshop (4 h) to map out the intervention plan, learning objectives and teaching activities, and (3) a final co-design workshop (4 h) to refine the plan and detail the activities. The characteristic for these workshops is the combination of hands-on work in small break-out groups with plenary discussions, and the visual and 'generative'

Fig. 4 Participants used inspirational cards to design the contents and the process of a 5-day intervention

Fig. 5 Educational activities during the research intervention

way of working by mapping out the intervention on big sheets of paper in the form of a scenario (see Fig. 4). Ten teachers and 7 to 9 researchers participated in the different co-design workshops. One researcher acted as the lead facilitator and time keeper, whereas the other participants were divided into three break-out groups with an almost similar number of teachers and researchers.

Tangible outcomes of the second phase include three intervention scenarios and walk-through videos, transcripts of plenary discussions at the end of each session, online documents with detailed procedures of teaching activities and supporting materials (e.g. templates, selection of off-the-shelf and new technology tools). As for intangible outcomes, the second phase enabled further mutual learning between participants as well as the establishment of a core group of three teachers who would take a leading role in the intervention and help the researchers with the final preparations (e.g. further detailing of the activities, translating materials to Danish).

The aim of *Phase 3: Intervening* was to explore the suitability of the educational activities for students with the objective to foster learning about technological aspects and implications of emerging technologies. A further aim was to provide teachers with the opportunity to familiarise themselves with this new subject and collaboratively explore how to teach it. The intervention was conducted with a K-9 class, and consisted of five teaching sessions about ML and AR of half a day each and spread out over two weeks (Fig. 5). The core group of six researchers and three teachers facilitated the

learning activities. Typically, one teacher and one researcher would pair up to facilitate a particular activity, with the remaining teachers providing additional support and the researchers taking the role of observer. These teacher-researcher pairs changed a few times throughout the intervention depending on the required expertise to facilitate an activity. The school-intervention was followed by a debrief session (2,5 h) to share takeaways by walking through and commenting on the activities of the past intervention. 8 researchers and 10 teachers participated in the debrief session.

The third phase resulted in research data such as observation notes, pictures of artefacts produce by students (e.g. filled out templates, posters of design proposals), video recordings of 3 out of 6 student groups that were followed closely, and transcripts of short interviews with 8 students immediately after the last session.

The aim of *Phase 4: Scaling* was to create opportunities for sustaining and scaling the project with the community of practice (Smith & Iversen, 2018). In this project, we planned future interventions and dissemination activities that would lead to long term teacher engagement. Two sessions were organised in this phase: (1) a future workshop (2,5 h) to discuss preliminary research findings and map out opportunities for new interventions and long-term engagement, and (2) a closing workshop (4 h) to reflect on the participatory design process and its impact on teachers' practices during the past year. The future workshop was attended by the core group of three teachers, the two special consultants from the municipality and the same eight researchers who participated in the debrief session. The closing workshop was attended by all 11 teachers and 11 researchers who previously participated in the process (see Table 1). Tangible outcomes of the fourth phase were a draft outline for follow-up interventions as well as ideas for disseminating teaching practices and research findings. Intangible outcomes included continued support from the municipality, and a shared understanding of how complex technological aspects and implications of emerging technologies can be transformed into cross-disciplinary teaching practices for future generations.

Qualitative data collection and thematic analysis

The central question driving the PD process was 'how and what' to teach in K-12 about emerging technologies integrating both technical with humanistic aspects. From a research perspective, we were interested in how teachers' participation unfolded throughout this process.

In order to provide an answer to these questions, the following qualitative data was collected and curated.

- Researcher notes from the 1st and 2nd author, finalised within 24 h after a session or workshop (phases 1, 2, 4)
- Video recordings and partial transcripts of walkthroughs of three educational scenarios and online documentation of detailed teaching activities (phase 2)
- Transcripts of feedback discussion and debriefs, typically at the end of a session or workshop and about the following main topics: agenda items and how to proceed (phase 1), perceived challenges and opportunities of the educational scenarios (phase 2) and teachers' perspectives on how the process has impacted their practices (phase 4)
- List of ideas for new interventions and scaling opportunities (phase 4)

We used thematic analysis as described by Braun and Clarke (2006) to interpret the qualitative data. First, the video recordings were transcribed, read through the transcripts and noted down initial ideas. Second, three researchers discussed the initial ideas and then coded all transcripts by applying one or more inductive conceptual categories (e.g., increased interest/motivation, manifestation of ownership, technology understanding, shared perspective) to discrete parts of the data, usually one or a few sentences, indicating what the piece of data is an example of. This was an iterative process, akin to open coding (Strauss & Corbin, 1998) and in an ongoing dialogue with the second author. This process was repeated until all categories were saturated, meaning that continuing analysis would not have yielded new categories and further insights. Thirdly, the first and second author collated categories into potential themes that formed the centrepiece of the analysis, and gathered all data relevant to each potential theme, akin to axial coding (Strauss & Corbin, 1998). Both the categories and themes arose from the data and, in line with a constructionist epistemological tradition, are latent and interpretative rather than semantic and descriptive. Fourth, the first author reviewed the themes and verified whether they work in relation to the coded extracts and the entire data set. Fifth, she described and refined the themes and the overall story the analysis tells. Lastly, she produced a report of the analysis illustrated with compelling quotes from the participants, and related back the analysis to the research questions.

Results

From our data analysis emerged two main themes. First, the findings showed that workshop structures, materials and digital tools supported the transformation of the PD process into a catalyst for the development of a common future educational agenda. Second, we found evidence that facilitation strategies supported teachers' transformation from co-designers of the intervention into change agents in emerging technology education. In the following, we present the detailed findings. In the exemplary quotes, we will refer to the teachers and researchers in numbers (T01–T11 and R01–R11) and indicate their major teaching subjects (see also Table 1). A summary of the process can be found in Table 2.

Theme 1: Developing exemplary teaching activities as a catalyst for an educational agenda

The PD process was shaped by *mutual learning opportunities between the teachers and the researchers* about how to approach future emerging technology education. On the one hand, since the teachers had hardly any experience in teaching about emerging technologies, researchers' expertise focused on providing the teachers with exemplary themes, tools and knowledge about the subject. On the other hand, the researchers had less expertise in connecting learning goals and pedagogical approaches into activity design for the K-12 classroom and benefited from teachers' knowledge of how to approach their students and integrate these contents across different school subjects.

More specifically, our findings showed that the structure of the PD process enabled the teachers to start reflecting on possible ways to develop teaching activities in alignment with the specific learning goals about emerging technologies. The process was initiated by the scoping phase with an *openness about 'what and how'* to teach about emerging

Table 2 PD approach: Scoping, developing, intervening and scaling

Phase of PD engagement	Objectives	Methods	Outcomes/teachers' development
Scoping	Introduce project, build rapport and set long-term agenda	Open invitation to participate in the co-design process	Were not confined to a pre-set agenda and could determine themselves their degree of involvement
		Openness about 'what and how' to teach emerging technologies	Sufficient space to explore their own ideas and to contribute with their expertise in teaching
		Exploration of exemplary hands-on activities and tools during Kick-Off Meeting	Develop a common understanding about the characteristics of emerging technologies
Developing	Co-Design exemplary learning activities and materials for emerging technologies	Working in cross-disciplinary teams to integrate technical and societal issues of emerging technologies	Knowledge and expertise led to diverging perspectives which transformed into a shared understanding of opportunities for teaching about emerging technologies
			Teachers contributed with their expertise in teaching didactics, whereas the researchers could point towards specific techniques and tools
			Combining different school subject objectives from social sciences to mathematics within the agenda for emerging technology education
		Using different tools, materials to support to integrate interdisciplinary aspect of emerging technologies in teaching practices	Generative, hands-on and iterative way of work dynamics
			Common agreement on the intervention details by leveraging their individual expertise and providing inspirational themes and core aspects in emerging technology education
		Dialogic facilitation strategy (e.g. open-questions) to establish spaces for mutual learning	Leverage teachers' expertise in teaching activities across different school subjects and for the specific target age-groups
Intervening	Explore suitability of activities and materials for K-9 education	Co-facilitating learning activities during the intervention and feedback meetings	Gradually gained more confidence in contributing with their expertise to the process and took ownership for their ideas

Table 2 (continued)

Phase of PD engagement	Objectives	Methods	Outcomes/teachers' development
Scaling	Share research findings and plan long-term engagement	Co-designing teaching activities and materials	Increased teachers' interest and knowledge about emerging technologies in education Catalysts for integrating educational practices about emerging technologies in local schools Easily appropriate the teaching activities and materials and to adapt them to different needs for their everyday practice

technologies. During the kick-off workshop (Phase 1, Fig. 2), we set up an introduction about the technical characteristics of emerging technologies (see Fig. 1) and showcased possible scenarios of using emerging technologies in education to facilitate a common ground. For instance, the teachers explored and compared how to create ML models with a web-based tool called the Teachable Machine[1] and a tangible user interface named the Machine Learning Machine (Kaspersen et al., 2021) which enabled users to create and iteratively train their own data sets using pen and paper. For AR technologies, the teachers were invited to experiment with the feature of live language translations using the Google Translate app, with AR filters of the social media platform Snapchat or how to collect information of spatial data with the tool (Lunding et al., 2022). In the following workshops, we proposed the teachers' themes about ethical and societal implications of emerging technologies (e.g. emotion monitoring in the classroom, racial biases of facial recognitions systems, etc.) and co-developed together with them ways to integrate them into future teaching practices. We also presented them with design-oriented learning strategies that focused on supporting students' understanding of stakeholders' intentions related to an emerging technology and skills in redesigning alternative technology solutions. This open approach gave the teachers sufficient space to explore their own ideas and to contribute with their expertise in teaching. At the same time, the researchers only stepped in when our own expertise was crucial e.g. by providing insights about technological fundamentals or detailed descriptions of example learning activities. Hence, the overall process was driven by the teachers who had an overview of how to connect the learning activities to their teaching practices and students' needs. We facilitated the process and provided input and direction where needed. In this regard, a female Danish teacher (T02) pointed out: *'It was great that we could imagine any type of activity, everything was possible, and then we could make it happen. For example, when you created the AR application for us. In everyday teaching, we don't have access to these kinds of tools and are more limited.'* This comment highlights how teachers valued our workshops as a learning experience that opened space for exploration and imagination of a future agenda for emerging technology education.

Further, during hands-on activities the teachers gained experiences with ML and AR technologies and developed an understanding about the technical characteristics and about how to use these *exemplary digital tools for educational practices*. Since the teachers had no or little knowledge about the technologies, they needed insights and hands-on experiences in order to be able to engage in the PD process. Several findings from the analysis of the PD sessions showed signs that these initial experiences laid the ground for shaping teachers' overall understanding of the ways of how to integrate meaningful learning activities for the students in the intervention. For example, during workshop 2 (Phase 2, Fig. 2) one team discussed strategies to design an activity in which the students would use the Teachable Machine. The hands-on activity was introduced with the aim to measure students' emotion in the classroom inspired by examples from smart teaching evaluation systems based on facial recognition in China (Tang et al., 2020). A male special education teacher (T06) remembered when they had used the Teachable Machine in the kick-off meeting and explained that the hands-on activity would make students notice that *'the teacher can just suddenly see that I'm not doing anything'*. This example indicates that during the kick-off meeting the teachers did not only learn how to train a computational

[1] https://teachablemachine.withgoogle.com

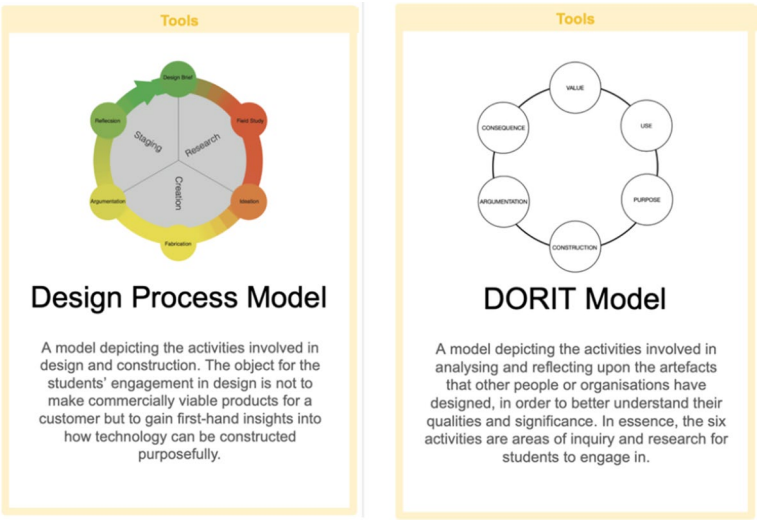

Fig. 6 Inspirational cards describing the "Design Process Model" and "DORIT Model"

model but they also experienced how to use it to make students aware of the implications of facial recognition technologies. Similarly, another group drew on their experience of using an AR application (Lunding et al., 2022) in which students could explore the concept of spatial data during the kick-off meeting. Specifically, they proposed an augmented crime game in which the students were asked to scan a room and to find clues about data that would help to reveal the murderer. In this example, a male teacher (T09, maths + biology) described that the students would not only learn about the technical features of the AR tool but also role-play being *'critical journalists'* in a press conference and *'explain the different clues (…), how they found them, (…) how it is connected to the real world they actually live in'*. In this sense, the students would be encouraged to critically reflect upon the trustworthiness of the collected data by presenting and argumenting for them.

Another core focus of our approach was to engage students in design activities around emerging technologies and their implications. The teachers were familiar with facilitating design thinking activities in digital fabrication workshops based on the "Design Process Model" (Dindler et al., 2020) which describes activities that are commonly involved in design projects (i.e. the design brief, field study, ideation and fabrication). It also integrates activities that support students' argumentation and reflection on how the technology that they design may affect people. In extension to this, we introduced the teachers to the "DORIT Model" (Dindler et al., 2023) which describes activities that involve analysing and reflecting upon the artefacts that other people or organisations have designed. Working with both models (Fig. 6) permitted the teachers to integrate meaningful and reflective exercises into design activities that we envisioned across different intervention sessions. For instance, we came up with the idea that students could redesign technologies for their own classroom. The design process entailed ideation and prototyping exercises but also an extensive mapping of stakeholders related to the technology at hand and their intentions in the light of the technology development and use (Schaper et al., 2022).

Further, to support the development of concrete learning activities and integration of technical and societal aspects of emerging technologies, we created *a set of inspiration*

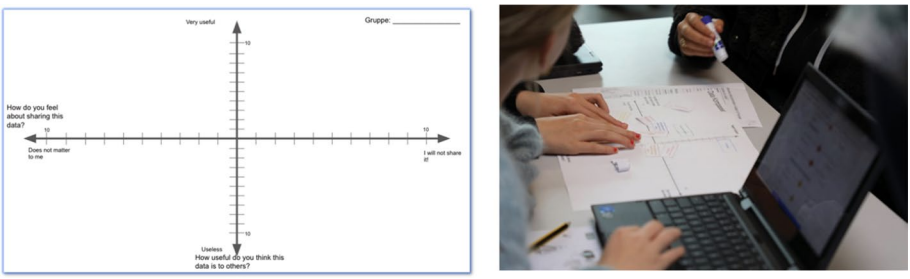

Fig. 7 Ranking activity to reflect upon personal data and their relevance for other stakeholders

cards prompting different contexts, exemplary learning goals, technology fundamentals, ethical and societal implications and tools/techniques in relation to emerging technologies (Phase 2, Fig. 4). This procedure allowed a generative, hands-on and iterative way of work dynamics and resulted in different educational scenarios for a five-day intervention. For instance, one team described an activity that would make students aware of data-driven technologies and their impact, i.e. how these technologies collect data and how the data could be used by others. To achieve this goal, the teachers proposed to work with personally sensitive data and with group dynamics that stimulate students' shared reflection process (Bilstrup et al., 2022). For instance, the teachers proposed a data-ranking activity based on a spectrum: from basic and non-personal data to increasingly more personal and potentially embarrassing data (Fig. 7). The inspiration cards helped the team to concretize the relevant aspects of their proposal. In the walkthrough presentation, the team explained *'…as a theme of our proposal we look at digital literacy and the technological understanding (…) and then we have these three areas: transparency, freedom and data, privacy and security. (…) Our thought is that everything in this project has to have some sort of hands-on from session to session, to keep the pupils motivated.'* In another team the inspirational cards supported the teachers and researchers in detailing how to integrate the activities into the school curriculum. A male teacher (T01, maths + religion) explained: *'We have chosen to work with this future classroom, and we see it in a combination with the subject Danish and mathematics (…) and probably also social science. And in connection with the Danish subject, we have thought of books (…) a science fiction perspective which then moves on to machine learning and how machine learning works.'* In other words, the cards helped the teachers and researchers to find a common agreement on the intervention details by leveraging their individual expertise and providing inspirational themes and core aspects in emerging technology education.

To explore future educational practices across disciplines and fields, we worked in *cross-disciplinary teams* between teachers and researchers. Participants' diverse knowledge and expertise allowed them to openly explore 'what and how' to teach and led to diverging perspectives which transformed into a shared understanding about opportunities how these themes could be integrated into existing subjects and teaching practices. For instance, during co-design workshop 3 (Phase 2, Fig. 1), a female teacher (T08, maths + physics) elaborated on the concrete framing of a learning activity in which students would use their own data to learn about the concept of a model of AR technologies in the context of a crime game. She described: *'The students need both, to analyze the data and conclude something. They need to be ready to hold a press conference.'* Complementary to this idea, one researcher (R04) suggested that the students could use the Ethical Matrix tool (DiPaola et al., 2020) *'as an activity in which the students analyze which stakeholders were involved*

in the crime.' In another team, one researcher (R01) suggested: *'We could provide the students with a template with six pictures and you can write on, draw (…) a simple storyboard.'* A female Danish teacher (T07) followed up on this idea: *'I would focus on the utopia vs. dystopian (perspective) and make them concentrate on what works in the beginning and how it can go wrong. Then you link to the science fiction book they were reading… at that age it is easier if you have a framing.'* These examples illustrate how the teachers contributed with their expertise in teaching didactics, whereas the researchers could point towards specific techniques and tools that support students' reflections upon emerging technologies and their ethical and societal impact. Nevertheless, the research process also showed that it took time to develop a shared language about project values and how to approach teaching in emerging technology education. Particularly, at the beginning of the process, we struggled with understanding each other, both between different academic fields, in our case computer science and humanities, and between academics and the teachers. Over time, we gradually grow together into the subject, sharing more openly ideas and opinions and vocabulary about emerging technology education.

Finally, the *co-designed teaching activities and materials* functioned as catalysts for integrating educational practices about emerging technologies in local schools. During a plenary discussion in the Closing Workshop (Phase 4, Fig. 1), a male teacher (T01, maths + religion) stressed that he had explored some of the learning activities from our interventions in his classroom. For instance, he used a fictional scenario as a starting point to introduce the students to the societal and ethical implications of emerging technologies. After that, he engaged them in an exercise with the Teachable Machine, to show the students how the technology would work in practice. He described: *'We talked about how we learn. Students often learn by example. (…) We created examples of competent teachers and bright students. Then, we made the machine recognize between these two.'* A science teacher (T11) explained that he planned with another colleague to create a new curriculum for an elective course named 'Digital Worlds'. He highlighted: *'We thought about bringing it into our classes because it fits with what we want to teach. It is something that is needed in the school.'* The examples show how both teachers were enabled to integrate different themes about emerging technologies within the subjects that they usually taught (e.g. maths, religion and science). Hence, the PD process supported them in easily appropriating the teaching activities and materials and adapting them to different needs for their everyday practice.

Overall, the careful scaffolding of the workshop structure, tools and materials allowed the teachers to engage in the PD process without a pre-defined agenda about 'what and how' to teach emerging technologies. Despite teachers' prior limited knowledge, hands-on experiences during the workshops provided an important inspirational component for them and allowed them to develop together with the researchers a common understanding of a possible future agenda for emerging technologies in education.

Theme 2: Teachers evolving towards change agents

The PD process supported the evolution of teachers' roles throughout the process. First, they showed an increased interest and knowledge about emerging technologies in education. Second, the teachers gradually gained more confidence in contributing with their expertise to the process and took ownership for their ideas. To support teachers' development during the PD process, we addressed the teachers with an *open invitation* to participate in the workshops, i.e. they were not confined to a pre-set agenda and could

determine themselves their degree of involvement. Reversely, they were able to shape or co-develop the process with the researchers, in a continuous dialogue where their perspectives and input were taken seriously. For instance, from the teachers who participated in the kick-off meeting only three teachers committed to participate in the core group. They actively participated in all workshop sessions and also facilitated the learning activities during the intervention (Phase 1–4). This was a gradual and not straight forward process where we supported and structured teachers' involvement and the steps in the process. Throughout, the teachers increasingly took on more responsibility and became change agents beyond the duration of the process by exploring example activities from our project in their own everyday practice. The other teachers mainly attended when project outcomes were presented and their expert feedback was beneficial to move the project forward (e.g. Phase 3 in the debrief meeting and Phase 4 in the Closing Workshop).

To facilitate the PD process, the researchers intervened with *open-questions* that would leverage teachers' expertise in teaching activities across different school subjects and for the specific target age-groups of the students within K-12 education. In the following example from workshop 3 (Phase 2, Fig. 1), a female Danish teacher discussed how a science fiction book could be used to introduce ML to 8th grade students.

> T07: *The idea about science fiction is that when you use this kind of reading then you can look into society (…) science fiction looks at the problem in the world of machines. (…) I'm a Danish teacher, I think that's a great part of session four as (…) a reading activity that works throughout all of the sessions (…).*
> R01: *How would you do this in session four? At the moment, there is a proposal but it could be something completely different than to write another science fiction story. Do you think there should be different activities?*
> T07: *I think the writing part would be a great way of summing up if they understand how this is problematic and if they can do a storyline where this goes wrong, and if they aren't aware of the problems concerning these technologies.*

The example also illustrates how a teacher inexperienced with technology education was able to create a space for her own teaching practices into the ongoing discussion. In this regard, the coordinator of the teachers' group (T01) stressed during the final project workshop: '*This project gave us the possibility to do new things, to move into new areas of expertise or non-expertise.'* These findings may indicate how this dialogic facilitation strategy allowed a strong focus on mutual learning in which *everyone's expertise was valued.*

Finally, in the Closing Workshop, we observed signs for teachers' interest to share their knowledge with the community of practice. For instance, a science teacher (T11) emphasised in the closing workshop presentation: *'We can use this (project) as an example to teach other types of emerging technologies. If these activities can be done by us, then also other teachers (…) can do it. (…) When teachers get to teach it more than once, it becomes easier.'* This example illustrates how the PD process allowed the teachers to become more confident after several sessions to talk about approaches for different kinds of learning activities that would integrate both technical aspects of the technologies and ethical implications.

Overall, the PD process was guided by offering the teachers opportunities for flexible participation and personal development. Further, it helped us explore multiple ways to bridge different school subject objectives from social sciences to mathematics within a future agenda for emerging technology education.

Discussion

In this article, we have presented a PD process with 11 pioneer teachers and 11 researchers in Aarhus, Denmark. The goal was to co-design teaching practices that could be sustainable within the existing community of practice of Danish education. Therefore, we explored and developed exemplary models for emerging technologies. Our results highlighted how the PD process became a catalyst for the development of a common future agenda. Furthermore, the results also showed that the PD approach supported teachers' transformation from co-designers into change agents in emerging technology education. To guide this process, we have built on the PD approach proposed by Smith and Iversen (2018) focusing on collaborative development of interdisciplinary teaching and learning practices around ML and AR for K-12 education. In contrast to other educational development projects (van Mechelen et al., 2022), we actively involved the teachers throughout the entire research process, i.e. they took a leading role in the preparation of the learning activities, facilitation and iterative evaluations of the outcomes. We will now reflect upon how this PD approach contributed to address the four core challenges in emerging technology education described previously, which were (1) the lack of teachers' and researchers' experience with the subject; (2) the difficulty to teach about the complex and uncertain characteristics of emerging technologies; (3) the need for novel strategies to engage students in learning about them; (4) strategies to scaffold long-term engagement with teachers and sustainable communities of practice in emerging technology education.

In the project, we aimed at investigating strategies that enable researchers and teachers to explore and develop flexible, engaging and cross disciplinary teaching practices for future emerging technologies education. Thus, our research team focused on the unique perspectives of teachers (Woolner et al., 2007) to be engaged in setting the future agenda for applying emerging technology education into practice. We aimed to respond to the requirements of highly digitized contemporary societies (Smith & Iversen, 2018) and the need to support students' understanding of digital skills and literacies through the concept of Computational Empowerment (Dindler et al., 2020) in specific relation to complex technologies and systems. To achieve these goals, we began with '0 stage activities' before the actual PD process was initiated which allowed teachers and researchers to develop a common understanding about the characteristics of emerging technologies. This procedure was essential for the PD process in order to improve the dialogue between the participants and establish a symbiotic agreement (Dindler & Iversen, 2014) on the project goals. Further, through working in cross-disciplinary and interdisciplinary teams and using dialogic facilitation strategies, we built mutual learning opportunities and a common understanding of technological artifacts as digital tools, educational environments and ways of engaging with the real-life issues around emerging technologies. Our approach has also highlighted the challenges that cross- and interdisciplinary collaborations entail. An important learning for us was that such collaborations require time to build up participants' confidence and to develop a shared language about learning goals, content, project values and practices.

On the other hand, to transform the abstract, complex and uncertain characteristics of emerging technology into teaching practices (Boon & Moors, 2008; Millea et al., 2005; Rotolo et al., 2015), we presented in this article new ways of co-exploring 'what and how' to teach about these technologies and strategies to engage students in learning about them. Our PD approach allowed us to move beyond a technical perspective on emerging technologies and to integrate aspects about their ethical and societal implications into the teaching materials. Specifically, teachers coming from humanistic subjects (e.g. Danish or religion)

had a crucial role in interweaving transdisciplinary aspects about emerging technologies into exemplary educational practices. Nevertheless, we also experienced that some teachers, particularly coming from STEM subjects, had difficulties to imagine ways to combine technical and humanistic perspectives for emerging technology education. Often our proposals were seen as teaching "soft-skills" about technology since they focused less on the acquirement of computational thinking skills. These experiences call for more initiatives in the field to develop exemplary learning that bridge both worlds between humanities and STEM subjects and stimulate a shift in traditional teaching practices. In future work, we have planned to iterate on our approach, i.e. we aim at addressing other emerging technologies such as Facial Recognition systems and internet of things technologies. Further, we plan to provide the educational community, on a national and international level, with a set of principles to design learning activities, exemplary learning activities and materials for emerging technologies in K-12 education.

Another goal of the project was to research strategies to scaffold long-term engagement with teachers that lead to sustainable communities of practice of teaching emerging technologies. Hence, we invited the teachers to participate in the PD process without constraining it through a pre-set agenda and fixed roles of involvement. Our approach showed to support the essence of genuine participation (Simonsen & Robertson, 2013) in the PD process which considers participants willingness of involvement in a PD project respecting the common project goals at hand. This approach set the ground for our ongoing collaboration with the teachers through the project, i.e. after this phase we formed a core teacher group who committed to the entire PD process and actively contributed to our project. These core teachers also assumed an important role in co-teaching the learning activities (Nicholson et al., 2022). Through this process, they gradually gained more confidence in teaching about emerging technologies and took ownership of ideas that we explored through the different learning activities. Further, the teachers reported on ways how they were able or plan to adapt exemplary learning activities and materials resulting from our project to different needs for their own everyday practice. We consider these outcomes as a first step towards the scaling of our project and illustrate its potential for the long-term engagement of stakeholders in the PD process (Bødker & Kyng, 2018; Tuhkala, 2021). However, we need to acknowledge that the project counted with the support of Aarhus Municipality and the necessary infrastructures that allowed a long-term engagement between teachers and academics. Researchers in other countries (e.g. United Kingdom and United States) are often constrained by legal restrictions and contextual factors (Braun et al., 2011) when involving participants from schools and the educational community which make it difficult to establish ongoing collaborations between research and practice. We believe these challenges can be addressed by using our PD approach as an inspiration and applying the four phases "Scoping, Developing, Intervening and Scaling" in a flexible manner that adapts to each educational context and reality.

Overall, our PD process followed a bottom-up research approach, building on the expertise of communities of practice in emerging technology education. The PD process enabled teachers with diverse experiences and competences to actively participate in the exploration of highly specialized and complex topics about emerging technology. To achieve this, the PD process was scaffolded with a particular view to engage diverse teachers, subjects and professional competencies into the nascent field of emerging technology, and thus demanded particular invitations, openness and support for Computational Empowerment (Iversen et al., 2018). Particular to emerging technology characteristics, the exemplary case of this study highlights the need for flexible practices where people with limited technical knowledge can contribute with their own knowledge and perspectives. For example, we

deliberately sought to engage some of the female teachers who teach in 'soft' or 'creative' subjects with the more predominantly 'male' and technical perspective. This was carefully crafted into the process by the researchers from social sciences and humanities who led the PD process, and the project's ambitions for a long-term field of practice in the creating structures and networks for a sustainable community of practice. We invite scholars to explore our approach as a means to engage practice communities into the discussion and development of future agendas towards a sustainable social change in emerging technology education.

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Declarations

Conflict of interest No potential conflict of interest was reported by the author(s).

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