Informatics in Education, 2024, Vol. 23, No. 2, 323–360

DOI: 10.15388/infedu.2024.15

Pedagogical Framework for Cultivating Children's Data Agency and Creative Abilities in the Age of AI

Juho KAHILA[1], Henriikka VARTIAINEN[1], Matti TEDRE[2], Eetu ARKKO[2], Anssi LIN[2], Nicolas POPE[2], Ilkka JORMANAINEN[2], Teemu VALTONEN[1]

[1]*School of Applied Educational Science and Teacher Education, University of Eastern Finland Joensuu, Finland*
[2]*School of Computing, University of Eastern Finland, Joensuu, Finland*
e-mail: juho.kahila@uef.fi, henriikka.vartiainen@uef.fi, matti.tedre@uef.fi, eetuark@student.uef.fi, anssilin@student.uef.fi, nicolas.pope@uef.fi, ilkka.jormanainen@uef.fi, teemu.valtonen@uef.fi

Received: September 2023

Abstract. The integration of artificial intelligence (AI) topics into K–12 school curricula is a relatively new but crucial challenge faced by education systems worldwide. Attempts to address this challenge are hindered by a serious lack of curriculum materials and tools to aid teachers in teaching AI. This article introduces the theoretical foundations and design principles for implementing co-design projects in AI education, empirically tested in 12 Finnish classrooms. The article describes a project where 4th- and 7th-graders (N = 213) explored the basics of AI by creating their own AI-driven applications. Additionally, a framework for distributed scaffolding is presented, aiming to foster children's agency, understanding, creativity, and ethical awareness in the age of AI.

Keywords: artificial intelligence, machine learning, sociocultural theory, data agency, participatory learning, curriculum co-design, distributed scaffolding, design-oriented pedagogy, pedagogy, K–12, schoolchildren.

1. Introduction

In recent years, a significant technological shift has sparked discussions about the necessity of revising computer education across all levels of education (Shapiro *et al.*, 2018; Shapiro and Fiebrink, 2019). Traditional rule-based automation has been accompanied by artificial intelligence (AI), particularly machine learning (ML), which has been accelerating automation in society, the workplace, and people's daily lives (Denning and

Tedre, 2019; Rahwan *et al.*, 2019; Tedre *et al.*, 2020). As AI has become infrastructural to cultural practices and everyday life, it has also created various calls for new kinds of digital competences that should be acquired by all citizens to ensure personal development, social inclusion, and active citizenship (Vartiainen *et al.*, 2022).

On the one hand, understanding both the power and limitations of AI is said to be crucial for agentive citizenship, as well as for the prosperity of democratic societies (Hintz *et al.*, 2019). On the other hand, the complexity of human agency is becoming a focal point of critical discussions, as many aspects of everyday life, such as our daily interactions, actions, and information of all kinds, are increasingly being tracked, mediated, augmented, produced, and regulated by algorithmic governance (Kitchin, 2012). The proliferation of AI-based technologies, coupled with massive-scale data collection, has also given rise to a whole new realm of complex challenges and ethical dilemmas, such as uneven power relationships, privacy rights violations, total surveillance, hybrid influencing, behavior engineering, algorithmic biases, and exacerbation of social inequities (e.g. Hendricks and Vestergaard, 2018; Kramer *et al.*, 2014; Valtonen *et al.*, 2019; Zuboff, 2015). As many people are unaware of how computational processes are re-engineering cultural practices and the decision-making processes of individuals, organizations, and institutions, there is a pronounced need to facilitate people in exercising and developing new forms of data agency (Vartiainen *et al.*, 2022).

To ensure that citizens can engage constructively, critically, responsibly and safely with practices of data driven society, researchers have called for new kinds of digital competences (Vuorikari *et al.*, 2016), AI literacies (Long and Magerko, 2020), data awareness (Höper, 2021), or data literacies (Pangrazio and Selwyn, 2019; Cu *et al.*, 2023). While the definitions of necessary literacies for the AI age differ, they typically emphasize competencies that enable people to critically evaluate AI technologies as well as abilities to effectively communicate and collaborate with them (Long and Magerko, 2020). Most AI literacy variants also highlight the need to understand how data are generated, processed, and used for different purposes (Pangrazio and Selwyn, 2019) as well as to learn the skills for solving discipline-specific or real-life problems by collecting, analyzing, evaluating, and interpreting data (Cu *et al.*, 2023). Yet, these literacies are typically described in a decontextualized manner, and many such AI frameworks are detached from the realities of everyday life (Palsa and Mertala, 2023) and disconnected from the development of agency that is essential for individuals to navigate and shape their digital environments.

Data agency, while overlapping with and complementing data literacies, refers to a contextual perspective on people's volition and capacity for informed actions that make a difference in their digital world (Tedre *et al.*, 2020). Data agency involves deeper procedural knowledge related to the data-driven world. This includes critical thinking required for challenging established norms and practices. It also involves the skills of making informed ethical and moral decisions, grounded in an understanding of the relational interaction of AI systems, epistemic practices, and social factors (see Shelby *et al.*, 2023). Moreover, the search for alternative possibilities demands creative abilities and a mindset rooted in data-driven design thinking, which may provide important pathways for seeking new, ethically sound solutions for pressing current issues and unforeseen future problems. In this respect, data agency calls for pedagogical models, practices, and scaffolding strategies that takes into account the socio-cultural practices and wider structures in which the agency is situated and where agentive actions are cultivated (Vartiainen *et al.*, 2022).

At this point, several literature reviews have identified a rising number of initiatives focused on teaching AI to novice learners. In recent years, these reviews have pinpointed AI literacy competencies and design considerations (Long and Magerko, 2020; Zhou, Van Brummelen, and Lin, 2020) as well as essential ideas, concepts and topics for AI education (Touretzky *et al.*, 2019; Tedre *et al.*, 2021; Tenório *et al.*, 2023). Additionally, there has been a focus on AI initiatives, instructional units, and tools (Marques *et al.*, 2020, Gresse Von Wangenheim, and Hauck, 2020; Sanusi *et al.*, 2023; Lim *et al.*, 2023; Heintz and Roos, 2021; Heinemann *et al.*, 2018), along with the evaluation of the effectiveness of such AI education interventions (Rizvi *et al.*, 2023). While much of the recent work on ML in K-12 has focused mostly on definitional issues, tools, and early interventions, much less attention has been focused on the underlying theories of learning and rigorous pedagogical foundations that inform the design and implementation of these instructional ideas and approaches. As noted by UNESCO (2022), there is also an evident need for involving various stakeholders in co-designing curriculum materials, tools, and scaffolding strategies for ensuring that the AI curriculums are pedagogically sound and actionable in practice.

In response to these pressing needs, this paper introduces the theoretical foundations, design principles, and cross-boundary co-design process that engaged teachers and researchers to co-develop new educational practices, curriculum materials, and educational technology for facilitating the learning of ML in K-9 education in Finland. In Finland, as in many other countries, AI is a new topic in schools, as well as in teacher education. There is a clear lack of context-bound curriculum materials, educational technology, and practices that support teachers in adopting ML as part of their teaching. Consequently, the research question for this paper was posed as follows: What key pedagogical elements and processes emerge from the co-design of a framework aimed at cultivating children's data agency and creative abilities when learning ML?

First, this article presents insights into the sociocultural approach to learning, focusing on some basic elements of mediated action that serve as crucial building blocks in the development of the learning environment and scaffolding strategies. Based on this theoretical grounding, the second section describes a pedagogical framework for transforming theories emphasizing participation, mediating artifacts, and tools into actual pedagogical practices. Third, this article introduces the notion of distributed scaffolding and the principles for orchestrating collaborative learning, which further guided the co-design of learning tasks, materials, and tools for learning ML. While the article does not involve analysis of empirical data, it provides a comprehensive description of the project, where 4th- and 7th-grade students (N = 213) explored the basics of ML by co-designing and creating their own ML applications. All of this comes together in the closing section, which presents a theory-driven and empirically tested framework for scaffolding children's agency, understanding, creative abilities, and ethical awareness in the age of AI.

2. Theoretical Foundations

The theoretical foundations underpinning this research and development work drew from classical sociocultural and cultural-historical theories of learning and participation, rooted in the pioneering work of Lev Vygotsky (1978) and his followers. At the time when psychologists were intent on developing simple explanations for human development, Vygotsky's central idea was that people's actions and thinking were mediated by cultural tools and artifacts, and by other people, such as peers, teachers, and experts during specific social activities. To Vygotsky, "mediated action" formed the basis for higher psychological processes, comprising interactions between the subjects (the actor or actors participating in the activity), the object of their activity, and the tools and artifacts that actors use for acting on the object (Cole and Engeström, 1993). Within this theoretical framework, learning can be understood as participation in social practices (Wenger, 1998) in which the activities are context-bound (Sfard, 1998) and mediated by different artifacts and tools (Schoultz *et al.*, 2001).

From a sociocultural perspective, our ability to carry out an activity is distributed across physical or psychological tools (Wells and Claxton, 2002). According to Wertsch (2007), mediated action involves a dynamic transition. Children first encounter cultural tools without fully understanding their meanings and functional roles. As children interact with these tools with the support of knowledgeable others, they gradually come to understand the meaning and functional role of various kinds of cultural tools with increasing levels of sophistication (Rogoff *et al.*, 1993; Wertsch, 2007). This implies that children's intellectual achievements and failures are not just dependent upon their individual abilities and efforts, but are distributed across the tools and social support that are within reach of the children (Vygotsky, 1978). Tools not only mediate or alter human activities, but also influence humans' mental structures (Edwards, 2007). From this standpoint, the overarching goal of instruction involves providing children with cultural tools and social settings that support increasing levels of expertise in using cultural tools flexibly and fluently (Wertsch, 2007).

Furthermore, Vygotsky saw that all tool-mediated activity is inherently social (Wells, 2007). He underscored the essential role played by experienced others, who can support the learning of the child by passing on the skills and knowledge from generation to generation through mentorship (Kozulin *et al.*, 2003). Vygotsky (1978) introduced the concept of the zone of proximal development (ZPD) as a key explanation for the role of collaboration and social mediation, defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 84). In other words, through joint activities with more experienced others, a child may be able to solve problems or complete tasks independently for which he or she does not yet have the developmental capacity (Vygotsky, 1978).

Overall, conceptualizing learning in sociocultural terms draws our attention to the multiple interacting elements of situated activities and particularly focuses attention on the relationships between material and social resources for learning and participation.

Thus, if we want to develop these interactions and create new kinds of tools, materials, and learning environments for participatory learning, there is an evident need to consider the relationships between people and resources that are formed in object-oriented actions. To transform these theoretical ideas into actual pedagogical practices, the following section discusses how the instructional perspectives of learning through collaborative designing can connect these elements in fertile interaction.

3. Pedagogical Framework

While research on students with agentive experiences with ML is in its infancy, at the same time, educational research and development work has, for a long time, explored the opportunities and foundations of learning-by-designing in science and technology education (e.g. Ching and Kafai, 2008; Harel, 1991; Hennessy and Murphy, 1999; Kodoner, 2002; Papert, 1980; Puntambekar and Kolodner, 2005; Roth, 1998). From a sociocultural standpoint, collaborative learning and design can be seen as an object-oriented process involving sustained efforts to create and advance epistemic artifacts and practices (Hakkarainen *et al.*, 2013). It further emphasizes the key role of social interaction in a jointly constructed activity, and the role of tools and mediating artifacts in the evolving and non-linear process of learning (Härkki *et al.*, 2020).

In short, design-oriented pedagogy stands out by emphasizing three key aspects that distinguish it from traditional instructional models. The first notable feature revolves around the nature of the objects of activities that organize and shape the process of learning. Unlike many existing instructional approaches that rely on scripted build-a-thing exercises or step-by-step coding tasks, the object is brought within this approach by engaging the students in the collaborative pursuit of open-ended, real-life problems (Hakkarainen *et al.*, 2013; Jonassen and Rohrer-Murphy, 1999; Krajcik and Blumenfeld, 2006). Such problems have no single solution or "right" answers; instead, they engage students in designing and developing different kinds of solutions by using the tools of the discipline in a manner similar to experts (Krajcik and Blumenfeld, 2006). According to Krajcik and Blumenfeld (2006), open-ended challenges drive the activities of the design project, provide a meaningful context for exploring new concepts and practices, and provide continuity to the full range of project activities. Likewise, Puntambekar and Kolodner (2005) have argued that design provides a meaningful context for learning content knowledge and skills, for understanding why concepts need to be learned, for seeing the contexts in which those concepts are put to use, and for relating those concepts to experiences both in and outside of school.

The second notable feature is related to the subject perspective, where design-oriented pedagogy moves from individual exercises to collaborative learning that aims to mirror the process of expert problem solving (Krajcik and Blumenfeld, 2006). It encompasses the idea that learning takes place through collaborative activities whose aim is to create new knowledge through work on shared objects (Paavola and Hakkarainen, 2005). By working together in small groups, students are expected to engage in active communication and the exchange of ideas, expertise, and prior knowledge (Hennessy and Murphy, 1999), as well as take responsibility for their learning (Damşa *et al.*, 2010). Through teamwork, students not only develop ideas and artifacts but also their collaborative skills, as they need to make decisions and compromise, negotiate roles and responsibilities, and plan and monitor joint activities (Seitamaa-Hakkarainen *et al.*, 2022). While design-oriented pedagogy emphasizes emergent processes that are formed and modified by students in the course of pursuing them, teachers nevertheless play a critical role in orchestrating these collaborative efforts (Viilo, 2020).

A third and equally important feature of design-oriented pedagogy is creatively working with externalized ideas and the materialization of thoughts with respect to creating epistemic artifacts (Hakkarainen *et al.*, 2013). The design process is always materially and physically distributed in terms of creating, using, and developing various external artifacts and tools that can significantly transform our cognitive competencies (Hakkarainen *et al.*, 2013). In other words, children are engaged in artifact-mediated knowledge creation by pursuing both conceptual (e.g. questions, spoken, or written ideas) and material (e.g. graphs, drawing, or prototypes) artifacts (Seitamaa-Hakkarainen *et al.*, 2012). Such multimodal interaction also makes students' ideas and reasoning processes more explicit as well as visible for joint evaluation and development (Blumenfeld *et al.*, 1991; Hennessy, 2011; Seitamaa-Hakkarainen *et al.*, 2012).

While some studies and practices of design-oriented learning have created the impression that students can deepen their skills and understanding on their own, it is important to understand that knowledge creation requires pedagogical infrastructuring and various kinds of support for student learning (Puntambekar and Kolodner, 2005; Viilo, 2020). The following section describes the fundamental elements that should be taken into consideration when scaffolding children's learning and collaborative design processes.

4. Scaffolding Collaborative Learning and Design

Effective participation in knowledge-creative approaches to learning requires a teacher's deliberate efforts in designing, planning, managing, and enacting collaborative learning processes (Littleton *et al.*, 2012). From a sociocultural perspective, the teacher is an important actor in orchestrating relations among the tools, materials, and supportive learning technologies, all of which interconnect and mediate the collaborative activities (Hämäläinen and Vähäsantanen, 2011; Littleton *et al.*, 2012). This orchestration of collaborative learning and design includes both pre-planning the project activities and afforded resources, as well as on-demand scaffolding during real-time activities (Hämäläinen and Vähäsantanen, 2011).

Scaffolding has been traditionally associated with Vygotsky's (1978) sociocultural theory of learning, and particularly with his idea of the ZPD, especially in terms of providing students with contextual guidelines or supporting resources for carrying out more complex activities that would otherwise be difficult to achieve. A fundamental idea in scaffolding also entails the adult providing appropriate support based on an ongoing diagnosis of the child's current level of competence or understanding (Puntambekar and

Hubscher, 2002). When children's understanding and skills grow, adults can gradually decrease their support until it is no longer needed (Brown *et al.*, 1989; Pea, 2004; Rogoff *et al.*, 1993).

According to Belland (2014), the early descriptions of scaffolding primarily linked it with a single, more knowledgeable person helping an individual learner. Thus, it was not associated with formal instruction and classroom activities in which a single teacher works with a whole class of 20–30 students (Belland, 2014; Martin *et al.*, 2019; Puntambekar and Hubscher, 2002; Puntambekar and Hübscher, 2005; Puntambekar and Kolodner, 2005; Tabak and Kyza, 2018). Scaffolding has thereafter evolved to include multiple affordances, such as curriculum materials, tools, and educational technologies used for supporting learning and collaboration (Martin *et al.*, 2019; Pea, 2004; Puntambekar and Hubscher, 2002; Puntambekar and Kolodner, 2005; Tabak, 2004). Thereby, the notion of distributed scaffolding was introduced, referring to a collection of material and social supports that enable children to learn disciplinary ways of knowing, doing, and talking (Puntambekar and Kolodner, 2005; Tabak, 2004). Likewise, Kim and Hannafin (2011) defined scaffolding as a dynamic approach in which learners are supported in accomplishing learning goals through the just-in-time and proper integration of multiple resources, including experts, peers, technologies, and learning contexts.

Furthermore, decades of pioneering research and theoretical development have been invested in the conceptualization and creation of educational technologies and scaffolding support for collaborative learning and knowledge building (e.g. Guzdial, 1995; Papert, 1980; Pea, 2004; Quintana *et al.*, 2004; Resnick, 2006; Scardamalia and Bereiter, 1993; Tabak, 2004). Consequently, the concept of scaffolding has also been employed to describe what features of the tools and the processes employing them are aimed at facilitating learning (Pea, 2004). According to Tabak and Kyza (2018), educational technologies can facilitate learners in tackling complex tasks that surpass their independent abilities, such as scientific modelling. This can be achieved by organizing, structuring, and coordinating the sequence of epistemic actions, and by delegating certain aspects of the task, such as complex computations, to the software. Moreover, software prompts, such as those that prompt learners to articulate, reflect, and regulate their progress in achieving task goals, can serve a role comparable to the guiding questions that a human tutor might provide (Martin *et al.*, 2019; Tabak and Kyza, 2018).

4.1. *Pre-planning*

While student agency and participation hold significance in design-oriented learning, the strategic planning and guidance provided by teachers plays a vital role due to their higher-level visions of the objectives of the projects (Viilo *et al.*, 2018). When planning school projects, the pedagogical model (e.g. learning through collaborative design) may provide macro-level structuring of educational activity by providing the principles and main phases (Sormunen and Viilo, 2022). Additionally, the notion of distributed scaffolding helps teachers design and prepare the contextual conditions in which the varied activities of the project should occur. According to Tabak (2004), there should also be a thematic continuity between tasks, materials, tools, and instruction aimed at mediating the key concepts and the critical features of the desired activity. Accordingly, this also requires the creation of plans and practical means through which to orchestrate and coordinate relations among these elements.

4.2. *On-demand Scaffolding*

Whereas research on teachers using scaffolding during real-time activities in design-oriented learning is scarce (Viilo, 2020), teachers, in particular, play a key role in scaffolding mindful and productive engagement with the task, tools, and peers (Tabak, 2004). According to Van de Pol, Volman, and Beishuizen (2010), teacher scaffolds strongly depend on the teachers' abilities to determine the children's current level of competence. This diagnosis of children's understanding can be made through various means, such as observing their individual or group activities, by asking questions, as well as by asking children to show or explain their work and lines of reasoning (Calor *et al.*, 2022). According to Puntambekar and Hübscher (2005), the ongoing diagnosis should be attained through dialogic and interactive relationships that position the child as an active participant. By asking questions and guiding children to elaborate on their lines of reasoning, the support of the teacher can also be tailored to the actual needs of the children – that is, made temporarily contingent, as Van de Pol, Volman, and Beishuizen (2010) have argued. There is a range of scaffolding means that may include, for example, enlisting student interest, controlling frustration, feeding back, providing hints or feedback, giving questions, highlighting the critical features of the task, demonstrating how an expert would approach solving a similar problem, and reinforcing children's self-esteem (Eshach *et al.*, 2011; Van de Pol *et al.*, 2010; Wood *et al.*, 1976).

Puntambekar and Hubscher (2002) noted that it is not usually possible for one teacher to provide tailored and just-in-time support for all the students in the classroom, as they are often too pressed for time. Thus, the focus of ongoing diagnoses and tailored support should be shifted to group activities (Puntambekar and Hubscher, 2002). Furthermore, within a classroom setting, fostering peer scaffolding can be a cost-effective and efficient means of providing support to all learners (Belland, 2014). Yet, collaboration and providing constructive peer scaffolding typically require guidance and collaboration scripts (Kim *et al.*, 2019) to help students in a team to work together productively, engage in respectful discourses, and take shared responsibility for the advancement of collaborative work (Seitamaa-Hakkarainen *et al.*, 2022).

Overall, various forms of scaffolding provided by tools, materials, and peers play an important role in supporting the work of teachers (Kim *et al.*, 2019; Puntambekar and Kolodner, 2005). Yet, the orchestration of emergent activities is always challenging, and thus, there is a clear need to offer teachers concrete resources, tools, and models to support collaborative learning and creativity, as noted by Hämäläinen and Vähäsantanen (2011). Thus, in the following section, we elaborate on how the above-discussed theoretical and pedagogical insights guided our co-design of learning tasks, curriculum materials, and tools for learning ML.

5. Co-designing the School Projects

This project is part of a long, multidisciplinary, design-based research (DBR) program that studies the integration of AI topics into school education (Toivonen *et al.*, 2020; Vartiainen *et al.*, 2020; 2021; 2022; 2023). In line with the DBR approach, the overall aim is to engage researchers, developers, and practitioners in a model of collaborative, iterative, and systematic research and development work through parallel processes of design, evaluation, and theory building (DBR Collective, 2003; Reeves, 2006).

Following the DBR approach, the co-design of the curriculum and related affordances was informed by previous research and related work, theories, and design principles that have addressed a similar or parallel problem (Reeves, 2006). In addition to previously presented foundational theories and insights on learning, our choice of pedagogical model, along with the concepts and topics of teaching, was guided by our prior empirical research. These base-line studies (Vartiainen *et al.*, 2022; Vartiainen *et al.*, 2023) and exploratory research (Vartiainen *et al.*, 2021) had found that the basic concepts and mechanisms of ML were unfamiliar to students and teachers, suggesting a need to create engaging entry points and scaffolding structures for novices to learn about ML. In line with the idea of designing AI curricula that are pedagogically sound and actionable in context-bound practices (UNESCO, 2022), the co-design of the curriculum highlighted the sustained collaborative endeavors between researchers and practitioners, who all brought their differing expertise in designing, implementing, and revising the prototypes of the designed pedagogical model, educational technology, and related curriculum materials (Penuel *et al.*, 2011; Reeves, 2006). Fig. 1 presents the framework used for cross-boundary co-design.

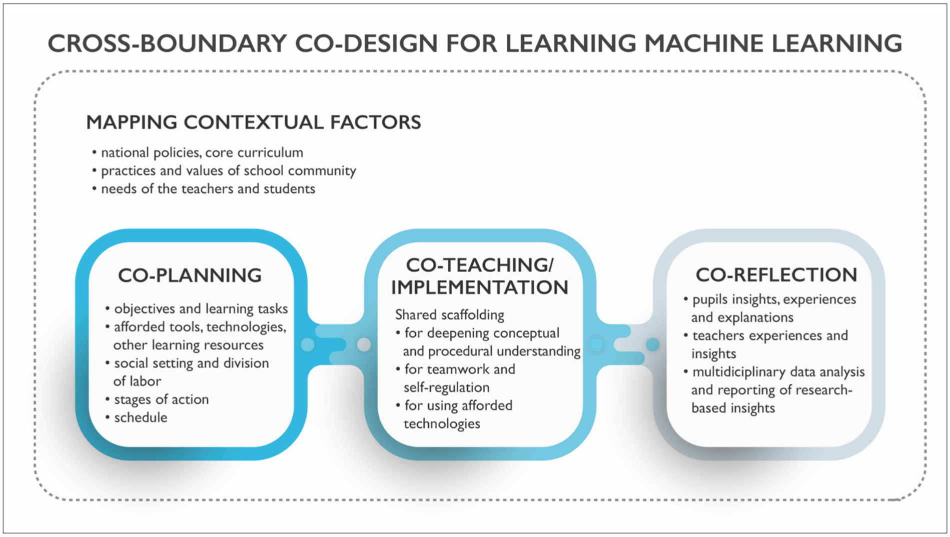

Fig. 1. Co-design of the school projects (Vartiainen, 2022).

5.1. *Mapping Contextual Factors*

This project team began collaborating with schools at the beginning of 2023 with an open call for participation. Participation was limited to the first 12 schools to enrol. A kick-off meeting was organized for teachers and principals in those schools to introduce them to the background, goals, and progress of the broader research program. The participants were asked to present their ideas and hopes for the school projects. After the kick-off meeting, the cross-boundary co-design process was facilitated by organizing regular joint discussions between researchers and participating school teachers. In addition to joint meetings with all the participating schools, each school was visited by one of the researchers to co-design and frame local design constraints, such as how the intervention could be customized to serve the local needs and interests of the collaborating schools.

In the research context of Finland, it is notable that Finnish teachers are highly educated professionals who possess a significant level of trust and autonomy in their work (Niemi *et al.*, 2018). Although the National Core Curriculum for Basic Education is regarded as mandatory, the Finnish education system does not include standardized testing, external audits, or outside teaching supervision. Instead, the Finnish education system places great emphasis on trusting teachers' professionalism, allowing them notable freedom in the choice of teaching and assessment methods as well as tools and materials (Niemi *et al.*, 2018). The importance of research-based approaches for developing educational practices is recognized at all levels, from the national strategy and policy levels to their implementation in teacher education (Niemi and Lavonen, 2020), providing fertile ground for cross-boundary research and development work.

The general objective of Finnish non-selective 9-year basic education, encompassing primary and lower-secondary school for pupils aged between 7 and 16 years, is to support pupils' growth toward humanity and ethically responsible membership in society and to provide them with the knowledge and skills needed in life (Niemi *et al.*, 2018). The curriculum is informed by a strong equity ethos, providing equal opportunities and high-quality teaching to every child regardless of their social, ethnic, or economic background (Niemi and Lavonen, 2020). Along with special subjects, the general frames of the Finnish National Core Curriculum focus on the development of seven transversal competences: (T1) thinking and learning to learn; (T2) cultural competence, interaction, and self-expression; (3) taking care of oneself and managing daily life; (T4) multiliteracy; (T5) ICT competences; (T6) working life competence and entrepreneurship; and (T7) participation in, involvement in, and building a sustainable future. These transversal competencies are to be introduced into local subject-specific curricula and implemented through project-based studies that integrate several school subjects. AI is not explicitly mentioned in the Finnish National Core Curriculum, but our efforts to promote children's agency and ML understanding through collaborative learning and design were well aligned with the Finnish National Core Curriculum.

5.2. *Making Plans for Joint Action*

In line with the theoretical foundations, pedagogical framework, and scaffolding principles, the joint planning of school projects focused on mapping the key elements of the desired activity system that should together enable the development of students' understanding of the basics of ML in a manner that builds their creative abilities. In practice, this meant creating a shared understanding of the broad patterns of the desired activity system (Engeström, 1987; Jonassen and Rohrer-Murphy, 1999), including 1) the higher-level objectives and learning tasks/problems that pupils face; 2) the tools, technology, and curriculum materials provided; 3) the forms of social organization (e.g. individual, small-group, and whole-class activities); and 4) the division of labor between the participating teachers and researchers. This also required the creation of a consensus on the practical coordination of the project activities (Vartiainen, 2022).

Throughout the project, and particularly during meetings between researchers and all of the participating school teachers, the four theory-derived perspectives listed above also served as a guiding framework for discussions and co-reflections together with the teachers. The teachers were not only asked to identify the development needs of the educational technology and related curriculum materials being developed but were also encouraged to reflect on how the activity system surrounding these new tools and materials was forming and how it should be improved.

5.3. *Designing Afforded Technologies and Curriculum Materials*

To support the design-oriented pedagogy, a new tool, GenAI Teachable Machine was developed (for further information, see Pope *et al.*, 2023). As a starting point, the tool design used Google's Teachable Machine 2, which is among the most popular image-classification tools used in education, and extended it with dozens of functionalities while keeping the familiar interface. Most importantly, the tool added the ability to bind actions to classification results, to open the finished classifier in a new tab as an "independent app," and share that app with friends through a QR code (Pope *et al.*, 2023). Its pedagogical design was based on the four previously discussed theory-derived perspectives that guided defining the relationship between the users (subjects) and the task (object) to be connected and mediated within particular social practices and tool-mediated actions. In other words, insights from mediated action were applied in the concept analysis, the design of the tool, and to enable an understanding of the context of use (Kaptelinin and Nardi, 2012).

In terms of the subject, the tool was designed particularly for school students in grades 4–9. Following the low-floor, high-ceiling, and wide-walls principle (Resnick and Silverman, 2005), our basic requirements were that children could begin to create their own classifiers with no prior knowledge of coding or ML while simultaneously inventing new ways of using the tool for their own creative purposes. Notably, promoting low barriers to entry and allowing personalized pathways were done in an attempt to promote equity and the participation of learners across diverse backgrounds (Kafai and Proctor, 2021). Furthermore, one key principle in the tool design was to respect children's right to privacy and to disallow any and all data collection that was not integral to the functioning of the tool (Pope *et al.*, 2023).

In terms of the object, our aim was to design a tool that would engage children in artifact-mediated knowledge creation (Hakkarainen *et al.*, 2013) by supporting them in expressing their own interest-driven ideas through co-designing, making, and sharing personally meaningful apps. Accordingly, the tool stands between the subject and the object of interest, and in this role, it helps the children to act on the object of interest by transforming ideas into digital artifacts. Additionally, the tool aimed to introduce novice learners to a number of central concepts and workflows in ML, particularly classifiers. Those concepts included classifier, class, name, example, training data, curation, training, input, confidence, actions, output, and deployment (Pope *et al.*, 2023). The technology was designed to engage children in the kinds of reasoning processes that would afford connections between their app designs and related disciplinary concepts in computer science.

Furthermore, the design of the tool involved defining a set of essential actions necessary for completing the desired activity (Jonassen and Rohrer-Murphy, 1999) – that is, the phases of the development process that the children needed to follow to transform their ideas into digital artifacts (apps). This was actualized by guiding the children to follow the basic epistemic functions related to the ML workflow for problem solving: how to collect data relevant to solving the problem, how to filter and clean the data, how to label the data, how to use those data to train a classifier, how to link the classifier results with desired behaviors (in a web app, for instance), and how to evaluate the model (Tedre *et al.*, 2021).

As argued by Quintana *et al.* (2004), educational technology designs should structure the functionality of the tool to support learners in observing and seeing what steps are possible, relevant, and productive. If this is properly provided, learners can also construct an understanding of the steps they need to take in their work. In this project, this was facilitated, for example, by using standardized icons and tooltips that guided the children on how to begin to build a classifier. Moreover, the tool divided the ML workflow into phases in order to decrease their cognitive load by structuring the process in ways that focused children's attention on the critical features of each (sub)task at hand. For example, the built-in scaffolding of the tool restricted the options visible to the learner so that the learner could only proceed to the build behavior after finishing their planning and prototyping of the classifier.

To motivate the children to follow the workflow to the end, the tool also provided room for children to personalize their projects by importing their own data (e.g. photos, voices, music, artwork, text, animations, graphics), and thus, they had the agency to affect their own course of action as well as the behaviors of the designed classifier. Moreover, the range of different data sources was intended to provide possibilities for the children to hybridize digital tools and media with non-digital activities (e.g. taking pictures or videos of physical objects, their own drawings, or craft work) in playful ways. This allowed the learning tool to be combined with other artifacts (digital and non-digital) to constitute larger-scale compound mediators (Kaptelinin and Nardi, 2012). No built-in scaffolds were included in the tool itself in order to maximize teachers' autonomy over the level of scaffolding, when and where to provide scaffolds, and how to integrate the tool with other classroom activities.

Furthermore, the tool was designed to facilitate learning by externalizing children's evolving ideas and reasoning processes. Children could test their classifiers and then iterate and refine their ideas and their creations, for example, by adding or removing classes, re-curating data, or changing the desired behaviors. This cyclic process of prototyping possible solutions could occur as many times as necessary to reach the desired outcome. Furthermore, the children could share their creations by deploying them in a new browser tab and providing a QR code that enabled the sharing of their applications with others (Pope *et al.*, 2023).

While the tool can be used in multiple ways and for facilitating different pedagogical visions, the above-discussed theory-derived perspectives together with previous research also guided us to analyze processes employing the tool in our school projects. As Jonassen and Rohrer-Murphy (1999) wrote, analyzing the context is essential for defining the larger activity system within which the tool-mediated activity occurs. Through an analysis conducted jointly between researchers and teachers, various kinds of curriculum materials were developed to enhance knowledge-creation and design-oriented activities in classroom settings. The basic idea was to assist children in thinking and talking about their design ideas and evolving artifacts by using the concepts and discourse norms of the discipline (Quintana *et al.*, 2004). In this way, the aim was to bring disciplinary ways of thinking closer to learners by making the key concepts and procedures visible in both curriculum materials and tool-mediated interactions. The following section provides a detailed description of the implementation of the school projects.

6. Implementation of The School Projects

The ML projects were implemented in 12 classes of 4th- and 7th-graders (N = 213) from Finnish elementary (grade 4) and secondary (grade 7) schools. These ML projects consisted of three workshops during spring 2023. Each workshop lasted between two and three hours, depending on the regular class schedule. As these projects fit the Finnish National Core Curriculum, they were implemented as part of regular curricular activity. Before the intervention, permission was obtained from the municipal educational administration as well as from the children's guardians, who were given a participant information sheet containing a study description stating that participation was voluntary and they had the right to withdraw, and outlining the data-collection details, data-processing methods, and the reporting of research results. The children received the same information about the study, and informed consent was given verbally at the beginning of the project, providing them with an opportunity to ask questions and to ask for clarification from the researchers.

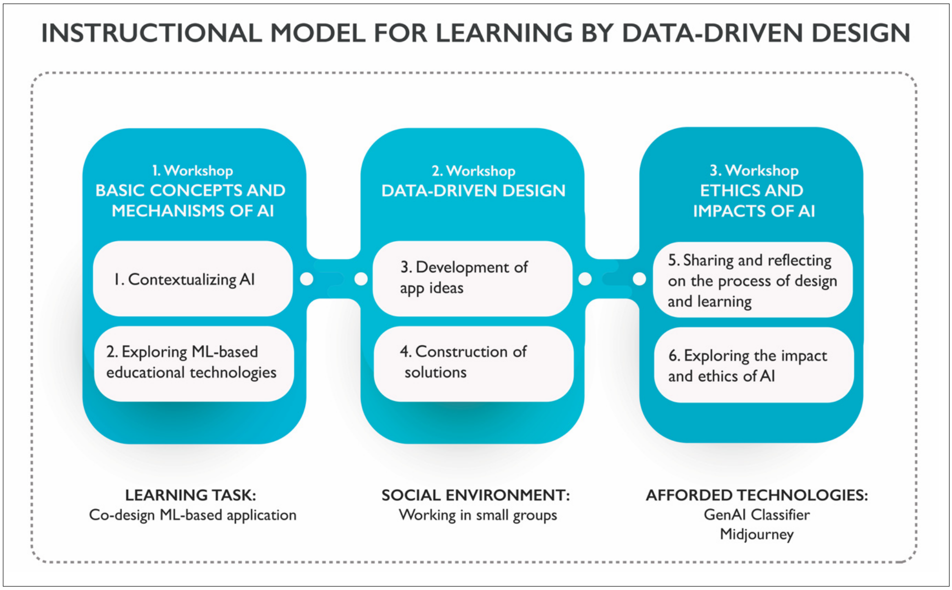

Fig. 2. Instructional model for learning ML concepts through data-driven design.

The researchers and teachers co-taught the student groups. One of the researchers, who is also an experienced classroom teacher[1], was responsible for teaching the ML topics due to a request made by the school teachers who had no disciplinary expertise. Yet, the schoolteachers played an important role in organizing the implementation of the projects as well as in guiding the students in working together and regulating their joint activities. Furthermore, two research assistants aided in data collection and the implementation of the school projects. Fig. 2 summarizes the workshop activities and the relevant elements of the learning environment (Vartiainen *et al.*, 2021). The general learning objectives of the project was to support children's data agency by fostering AI-related conceptual understanding, creativity and innovation, fluency with AI, workflows and practices, and ethical awareness (see Fig. 16). In addition, each workshop within the project had its own specific goals, as elaborated in the following sections.

6.1. *First Workshop: Basic Concepts and Mechanisms of ML*

The first workshop began with introductions, in which the researchers introduced themselves and provided an overview of the project, its aims, and implementation. They also informed the students about the research methodology and the data-collection process. In addition, the learning objectives of the workshop were introduced.

[1] As the researcher leading the implementation of the school projects was an experienced classroom teacher and took on the role of teacher when interacting with the students, he is referred to as a "teacher" in the detailed description of the project implementation.

Goals of the first workshop:

- Discuss AI, its applications, and its impact on everyday lives using tangible, contextualized examples.
- Introduce the basic concepts and workflows involved in creating an ML-based classifier.
- Engage children in the hands-on exploration of and collaborative experimentation with the classifier tool.

6.1.1. *Contextualizing AI*

The first workshop focused on contextualizing ML in students' everyday lives. In line with the scaffolding strategy of using examples and language that is congruent with students' everyday experiences (Belland *et al.*, 2013), the workshop began with a short introduction of the fundamental ideas and use cases of ML, such as recommendation systems, self-driving cars, spam filters, and social media advertising. While the introduction given by the teacher was actualized primarily by means of a lecture, it involved connecting students' interests through real-life examples that also provided a grounding for the subsequent task.

Following the introduction to ML, an individual assignment (Fig. 3) was given to the students. This assignment prompted the children to ponder how and in what ways ML was already a part of their everyday experience. In this anchoring experience (Krajcik

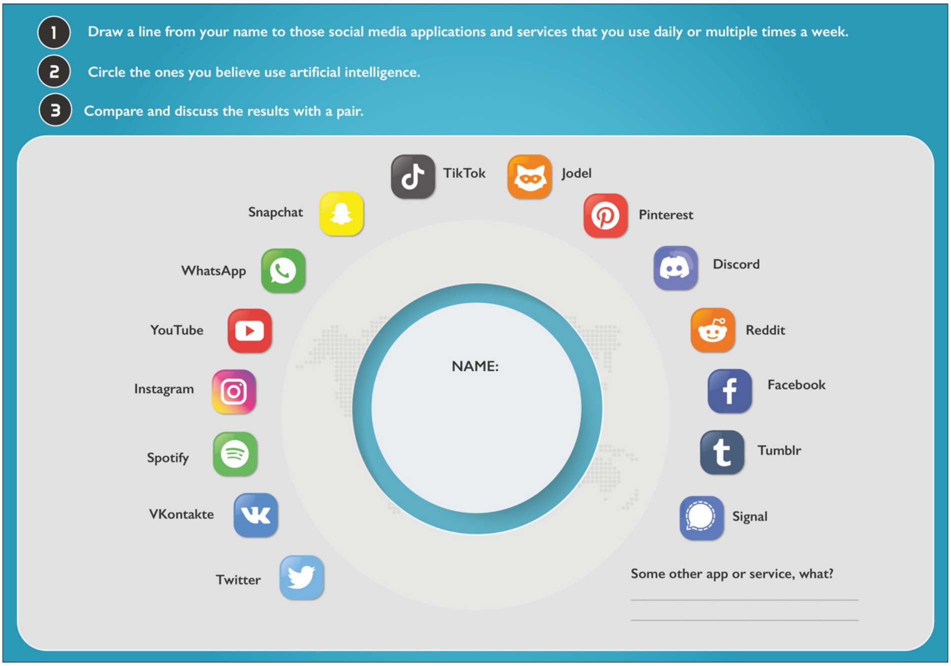

Fig. 3. Assignment on children's experiences with AI in social media.

and Blumenfeld, 2006), students were guided to analyze their use of social media applications and their understanding of the prevalence of AI technology in these applications. Then, the children were encouraged to compare and discuss their results with others.

The individual assignment was followed by the first group task (Fig. 4). Each group selected an app or service that used AI, often choosing from the options provided in the previous assignment. Subsequently, the material guided groups to discuss the type of data collected by the chosen application, how it was used, the purpose of collecting that data, and the potential risks associated with its use (Fig. 5). Teachers actively facilitated and supported the groups' work and task completion by asking students to externalize their ways of thinking and reasoning. These discussions also provided the teachers with an opportunity to review children's conceptions and existing knowledge about AI coming from their everyday experience and popular culture.

Finally, using YouTube as an example, the teacher explained how social media services categorize users based on their video preferences and interactions (such as thumbs-ups and thumbs-downs). The teacher also explained profiling and recommending, or how YouTube considers the viewing history of other users who watched the same videos, updating the list of recommended videos accordingly. The explanation also touched on targeted advertisements, or how YouTube combines its user information with Google searches to target ads at users. By using everyday examples, the teacher also provided an explanatory rationale (Belland *et al.*, 2013) about why understanding AI was relevant to students' current and future lives.

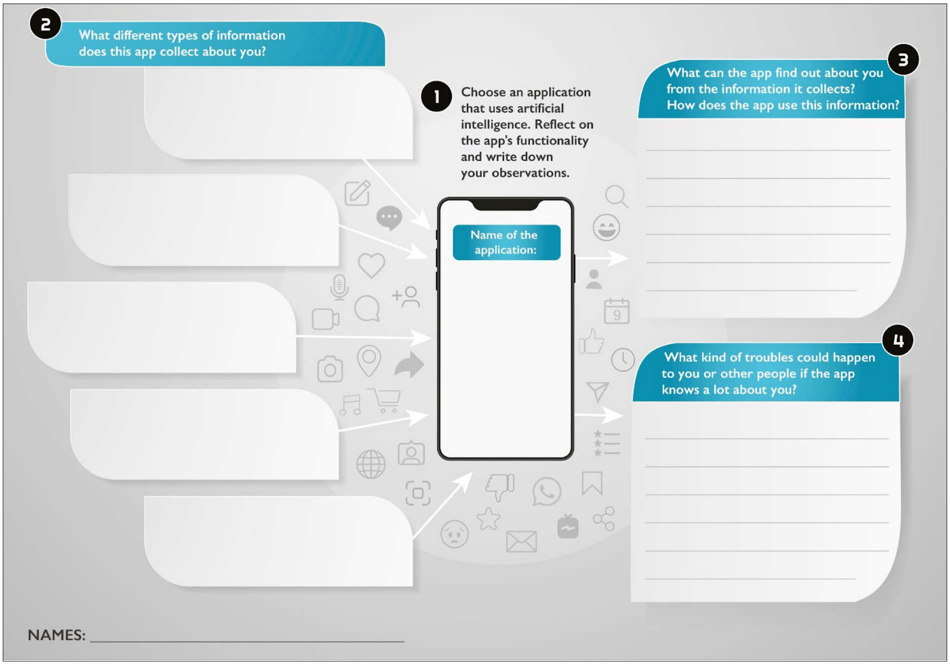

Fig. 4. Assignment on children's conceptions and existing knowledge about AI in familiar social media services.

Fig. 5. 7th-graders' collaborative exploration of everyday data traces with the guidance of curriculum materials.

6.1.2. *Exploring ML-based Educational Technologies*

In the second part of the workshop, the children were guided to familiarize themselves with the possibilities of our own in-house educational application for learning some principles of ML. The teacher demonstrated the ML workflow through a theoretical introduction as well as by giving a practical example (the rock, scissors, paper game). As the teacher verbalized the actions and thought processes when demonstrating the use of the tool (Belland *et al.*, 2013; van den Pol *et al.*, 2010), it gave the students an opportunity to observe the processes through which experts make use of basic conceptual and procedural knowledge (Collins *et al.*, 1989). This facilitated the students in beginning to build a mental model of the target processes that were required to accomplish the subsequent learning tasks.

After the ML tool and workflow were demonstrated, each small group was instructed to create its own classifier. The teams were given worksheets to facilitate the exploration of the basic concepts and mechanisms related to classifiers (Fig. 6 and Fig. 7). In terms of the training data, the teams could either use items found in the classroom or images downloaded from the Internet. The task was open-ended in nature, as the teams could create their own classifiers based on their own interests and thus modify the procedure the teacher had just demonstrated (Fig. 8).

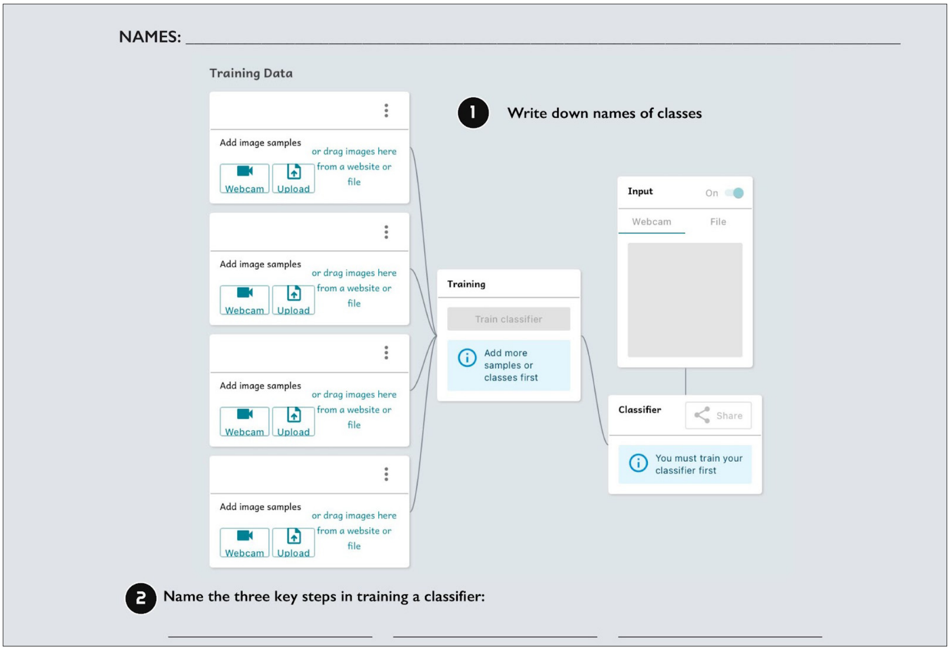

Fig. 6. Worksheet for working with students' own classifier projects and working with key concepts: class, label, sample, training data, data curation, and training.

Fig. 7. Worksheet for testing and debugging students' own classifiers and for exploring model brittleness, reliability, and confidence.

Fig. 8. 4th-graders explore the tool through peer collaboration and by using material artifacts.

The first page of the worksheets (Fig. 6) included questions regarding the classes and labels of the group's classifier and the steps involved in creating it. The second side of the worksheet (Fig. 7) provided guiding questions for children to test their classifiers and analyze their behavior. From the scaffolding strategy viewpoint, this activity indicated important concepts and mechanisms to which students should pay particular attention when familiarizing themselves with the tool. Moreover, during this hands-on exploration, the teachers actively observed the students' activities, and they provided on-demand support by offering hints, guiding questions, conceptual reminders, or short explanations of where children should look and what they should focus on in their exploration.

At the end of the first workshop, the teacher demonstrated how to add behaviors to the classifiers by adding them to the rock, scissors, and paper example created at the beginning of the workshop. This was done at the end of the workshop after students had learned how to make a classifier in order to separate the different stages of the workflow, and to avoid unnecessary cognitive overheads from having too many items and concepts (and icons to click) on screen. It was, however, timed for the first workshop and not the second to give students a complete picture of what kinds of apps could be developed with the tool.

6.1.3. *Brainstorming app Ideas*

The students were assigned an individual homework task (Fig. 9), which asked them to search for and identify everyday problems that could be solved by using ML/classifier-based technology. It is important to recognize that students can struggle to generate ML app ideas due to a lack of domain knowledge, which can reduce their motivation and confidence in accomplishing the tasks (Kim *et al.*, 2018). Thus, the ideation process was facilitated in the first workshop by supporting the development of conceptual and procedural understanding through collaborative activities and discussions around ML and the concept of classifiers. Furthermore, the ideation worksheet incorporated questions that encouraged students to come up with app ideas and prompted them to engage in data-driven reasoning when explaining practical implementations.

6.2. *Second Workshop: Data-driven Design*

The second workshop focused on co-designing and making applications based on the students' ideas. Prior to the students' arrival, the teachers read and analyzed the AI application ideas proposed by the students. These ideas were categorized as implementable, requiring significant redesign, or unfeasible. Upon the students' arrival, they were briefly briefed about the workshop's objectives and progress.

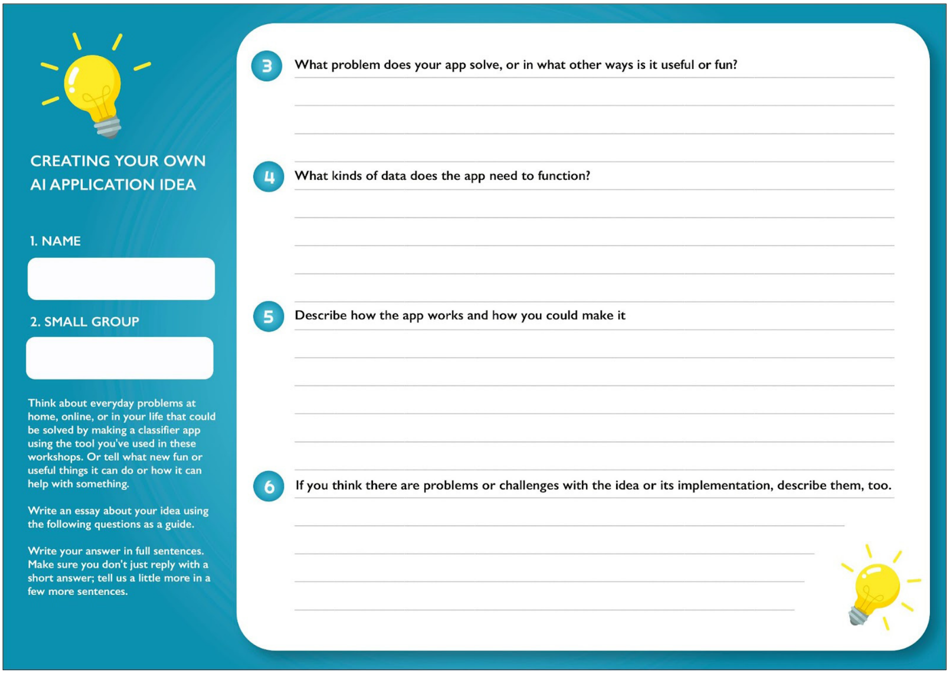

Fig. 9. Worksheet for describing one's own idea for a classifier-based app.

Goals of the second workshop:

- Facilitate the ideation, design, and implementation of the children's own ML (classifier-based) applications.
- Enhance children's understanding of the core concepts and workflows of ML.

6.2.1. *Development of app Ideas*

The groups were instructed to share and discuss their app ideas and select one for further design and implementation. The teacher walked from group to group and actively supported the teams in evaluating their ideas. Passing judgment on ideas was avoided (Eshach *et al.*, 2011). If all the group members' ideas were deemed unfeasible for implementation within the class timeframe and in light of other material resources, even with significant redesign, the teacher aided in generating new ideas that preserved the original theme as much as possible or were based on the group members' other interests. By doing so, the student teams were also facilitated in creating shared goals and constructing a shared understanding of the steps they needed to take in their work.

6.2.2. *Construction of Solutions*

For the second workshop, a design template was produced with the aim of supporting the further development of ideas through collaboration (Fig. 10). First, this template provided higher-level prompts (Puntambekar and Kolodner, 2005), as it visualized

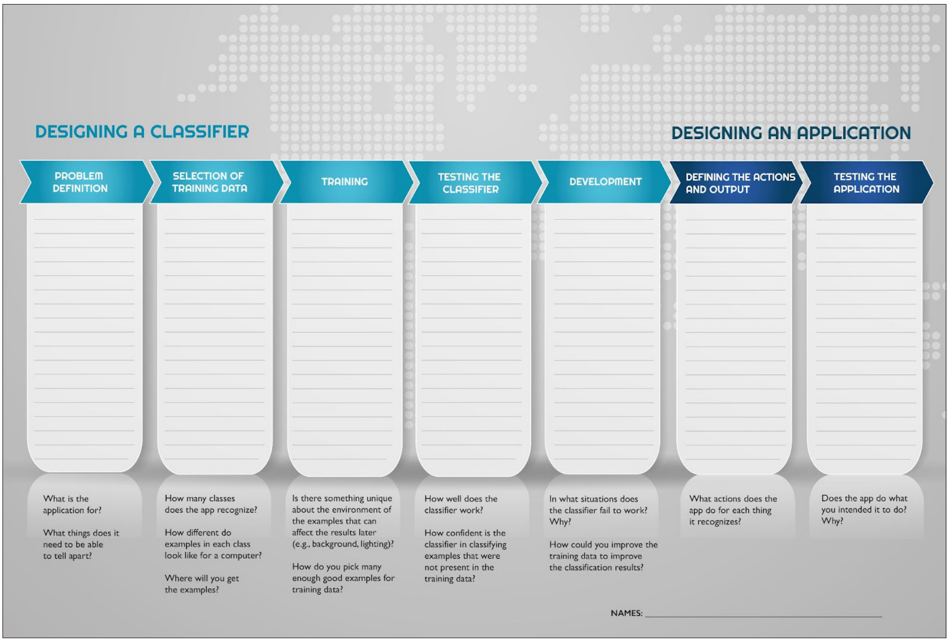

Fig. 10. A template for designing and implementing a classifier-based application, outlining all the steps in the students' workflow.

the whole design process and workflow as a whole. Second, it provided micro-level prompts for the sub-tasks within each phase (Puntambekar and Kolodner, 2005). These questions aimed to help teams to articulate their thoughts and ideas by guiding them to analyze, for instance, what their own apps would do, what kind of data would be collected and from where (image, poses), how many different classes the model should be able to recognize, and under what conditions the teaching data would be presented. Students further defined these externalized ideas in collaborative discussions with the teachers. By asking questions and guiding the teams to reflect on their ideas and to elaborate on their lines of reasoning (Van de Pol *et al.*, 2010), the teachers could then use that diagnostic information to, for example, direct students' attention to previously unnoticed aspects, such as the important role of the image background in webcam feeds. In this way, the content of the teachers' scaffolding was tailored to specific design ideas as well as emerging challenges that arose when the students were creating training datasets for their own ML applications (Fig. 11).

In addition, the curriculum material guided the teams to test their classifiers, explain their observations, and develop the application based on their testing and reasoning. In other words, the proposed solution ideas were tested, with explanations generated about why something did not work as expected (Puntambekar and Kolodner, 2005). As the students tested their classifiers, they were also able to receive immediate feedback from the interactive tool, and they needed to make decisions about whether and how to refine their current solutions. This guided the students to analyze the model behavior from a data-driven perspective, including assumptions and biases in the training dataset, labelling, the fit between the training data and input data, and the interpretation of outputs. When

Fig. 11. 7th-graders develop app ideas through dialogic discussion with the teacher, mediated by the learning tool and curriculum material.

iterating their designs by adding or removing labels or re-curating data, the children could also manipulate and observe how changes in the data corresponded to changes in confidence. The opportunity to collaboratively try out ideas, followed by the need to tinker with workable solutions, also aimed to model how unexpected outcomes and failures are a natural part of the data-driven design process. As argued by Belland *et al.* (2013), modelling constructive responses helps students use failures in the design and underlying thinking as formative feedback to improve learning and the artifact under construction.

Overall, the co-design process was facilitated in the second workshop by engaging students in sharing their initial ideas, negotiating a shared object of activity, making decisions about how to proceed, and then creating solutions through an iterative process of testing and refining the artifact under development. For that, the afforded curriculum materials and the tool provided guiding questions and hints on how to proceed and how to explain, verbalize, communicate, and develop initially vague ideas. Moreover, these collaborative discussions and support from the teachers were also aimed at helping student teams in planning, monitoring, and directing team-based creative activities.

6.3. *Third Workshop: Impact and Ethics of AI*

At the beginning of the third workshop, the children were again briefed on the workshop's objectives and progression.

Goals of the third workshop:

- Sharing and presenting the group's apps and projects.
- Analyzing the benefits, impacts, and risks of ML, including algorithmic bias.

6.3.1. *Sharing and Reflecting on the Process of Design and Learning*

In the third workshop, the teams were given group assignments (Fig. 12) that involved preparing a presentation about their own app and the process of learning and co-design. This curriculum material provided guiding questions aimed at supporting the teams to collaboratively reflect on the training process, consider the benefits and risks of their app design, and reflect on their own process of learning.

In these presentations, the teams also demonstrated their AI apps to their classmates, who could provide comments and ask questions on the presented projects (Fig. 13). The students were prompted to give constructive feedback, for example, by asking their classmates to elaborate on their ideas or to elicit articulation and justification (Belland, 2014). As each student team worked on its own problem, the teams were also able to observe multiple ways in which this tool and the related conceptual knowledge could be applied. The teams of children created 71 different apps. These applications were designed, for example, to recognize different emotional states, dance poses, memes, symbols, logos, hand signs, sports equipment, football players, music instruments, car models, poisonous mushrooms, different plants, animals, and dog breeds. Some apps were designed to tell jokes, recommend clothes to wear, and assist color-blind people to identify different colors.

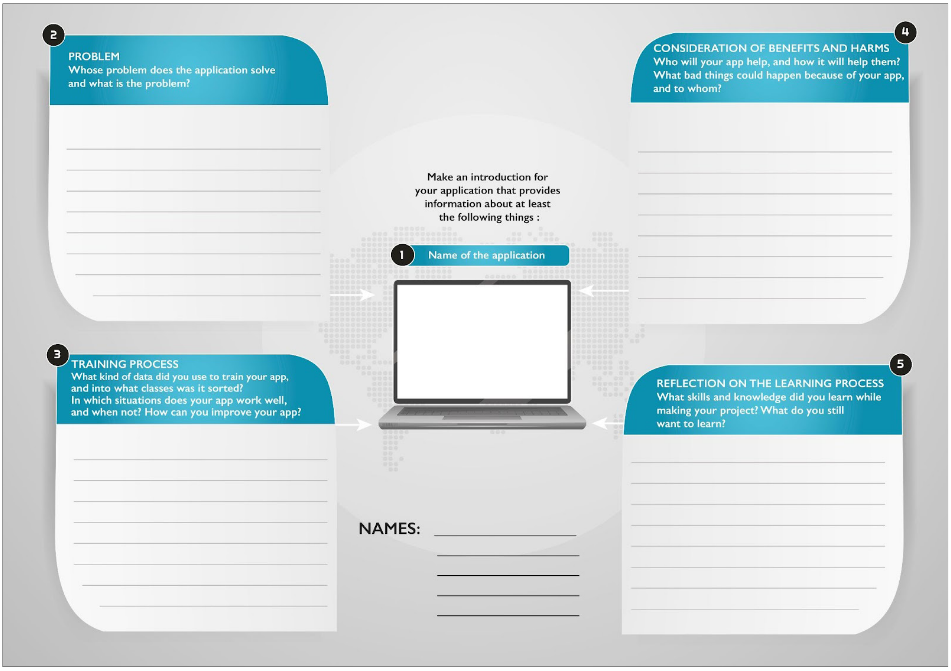

Fig. 12. Worksheet for reflecting on the ML workflow, benefits, and risks, as well as students' own views of their learning process.

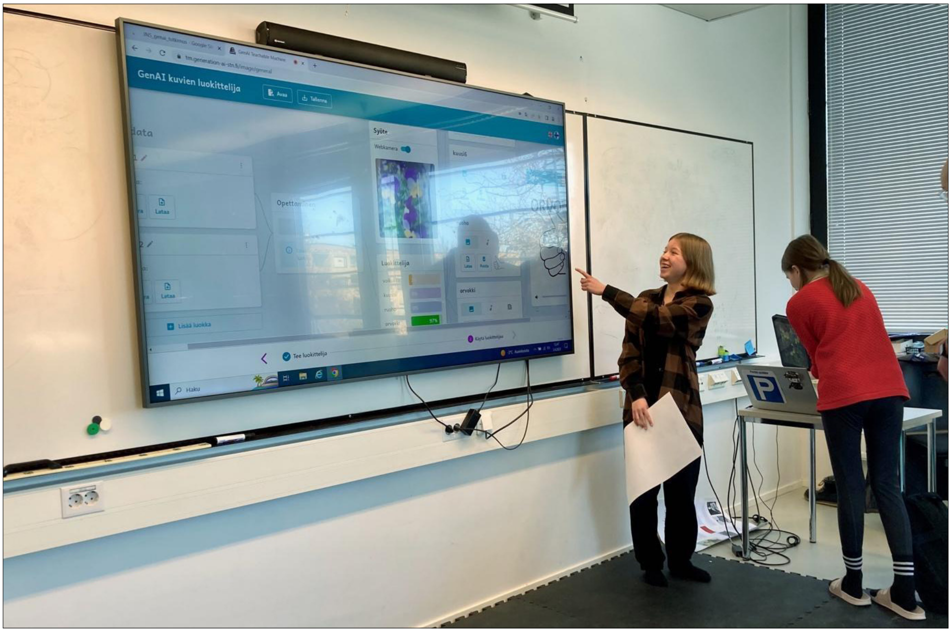

Fig. 13. 7th-graders sharing the process of design and learning in tool-mediated actions.

6.3.2. *Exploring the Impact and Ethics of AI*

After the presentations, the children were guided to further explore the ethics of AI, especially the concepts of algorithmic bias, through the use of generative AI. The topic was introduced by the teacher, who used the rock, scissors, and paper example from the first workshop, along with the participants' self-made classifiers, as an example for the use of manually labelled examples as training data. Then, the teacher gave an introduction to the mechanisms of image recognition, how web scrapers extract image–text pairs to train large image-recognition systems, and how those same datasets can also be used to make excellent text-to-image generative models. The concept of algorithmic bias was introduced by prompting text-to-image generative AI to make pictures of leaders (featuring only old white men) and classroom teachers (featuring only white women). Illustrative examples were used to discuss algorithmic bias, its causes, harmful effects, and potential corrective measures.

After the introduction, the children were instructed to work in small groups, create their own images, and examine the resulting pictures to identify algorithmic biases. Each group had access to generative AI on laptops, and the researchers provided individual guidance on image creation. As all the images were shared on the same Discord channel, the student teams were also able to see the prompts and images of their peers. Once the groups had their initial images, they were given a group assignment (Fig. 14), which asked them to document the algorithmic bias they had identified and its underlying cause, and to propose potential solutions for addressing the bias. The children were again facilitated in engaging in data-driven thinking, but by using a new concept and tool (Fig. 15).

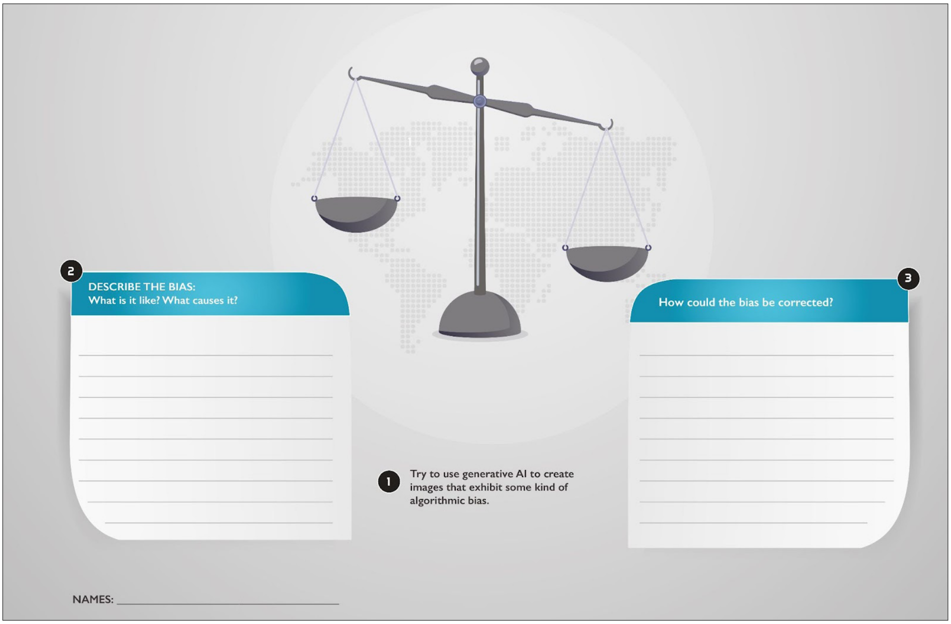

Fig. 14. Worksheet for exploring algorithmic bias using text-to-image generative AI.

Fig. 15. 7th-graders working with a text-to-image generative AI tool to explore algorithmic bias.

7. Discussion

Despite a significant surge in initiatives aimed at incorporating AI/ML topics into K-12 education, the aspect of distributed scaffolding has largely been overlooked in research and development efforts up to the present day. By connecting scaffolding with its theoretical foundations and with design-oriented pedagogy, this study demonstrates how these research-based insights can be employed in practice to develop learning environments, educational technology, and pedagogical models for ML education. By articulating how theories guided the collaborative design and orchestration of school projects involving over 200 students, this study aimed to give a comprehensive view of the interconnected components that form a system of distributed scaffolding for facilitating students' engagement, understanding, and agency.

By building on a design-oriented pedagogy, the fundamental principle in this study's approach was to position children as designers and knowledge creators (cf. Fischer *et al.*, 2004; Hakkarainen and Seitamaa-Hakkarainen, 2022; Kafai and Proctor, 2021; Resnick, 2006). This type of meta-design was aimed at avoiding being limited to a predetermined way of using the afforded tools and technologies, instead creating a learning environment that allowed children to act as designers, as advocated by Fischer *et al.* (2004). From a sociocultural standpoint, the aim was to facilitate children to move from more peripheral positions (Wenger, 1998) and assume agentially central roles, as they were developing their understanding and skills through joint activities with more experienced others (Damşa *et al.*, 2010).

Table 1

Distributed scaffolding for learning machine learning though design-oriented pedagogy

Phase	**Activity**	**Scaffolding strategies**	**Mediating tools and resources**
Contextualizing ML	Teachers' presentation	Using real-life examples that bridge learners' interests, intuition, and understanding	Presentation slides
	Individual and group work	Supporting learners to recognize and analyze how ML is part of the applications that they actively use	Curriculum materials (Figures 3 and 4)
		Prompting learners to share and compare their intuitive ideas and understanding	
	Teachers' presentation	Using real-life examples that bridge learners' interests, intuitive ideas, and understanding with data-driven explanations	Presentation slides
		Providing an explanatory rationale as to why understanding AI is relevant to students' lives and futures	
Exploring ML-based educational technologies	Teachers' demonstration	Demonstrating how to use the ML tool and construct data-driven explanations	Presentation slides Educational technology
	Group work	Providing a learning task that connects learners' own interests and lets them adapt the procedure the teachers had demonstrated	Educational technology
		Prompting collaborative reasoning about ML by making observations, testing conjectures, and developing explanations	Educational technology Curriculum material (Figures 6 and 7)
	Teachers' demonstration	Demonstrating how to use the ML app-creation tool and construct data-driven explanations	Educational technology
Brainstorming app ideas	Individual work	Providing a learning task that enables learners to generate ideas connected with their own interests and externalize them	Curriculum material (Fig. 9)
Development of app ideas	Group work	Prompting learners to share, evaluate, and develop ideas through peer collaboration and by using disciplinary concepts and strategies	Curriculum material (Fig. 10)
		Prompting learners to create a shared object of activity and plans for joint action	
Construction of solutions	Group work	Prompting learners to externalize their conjectures and refine conceptions by testing their designs and analyzing the results through peer collaboration	Educational technology Curriculum material (Fig. 10)

Continued on next page

Table 1 – continued from previous page

Phase	**Activity**	**Scaffolding strategies**	**Mediating tools and resources**
Sharing and reflecting on the process of co-design and learning	Group work Whole-class discussions and presentations	Prompting learners to reflect on and share their process of learning and design by using concepts and disciplinary strategies	Educational technology Curriculum material (Fig. 12)
Exploring the impact and ethics of AI	Group work	Prompting learners to connect concepts and disciplinary strategies to explore, question, and critique the implications of AI applications	Text-to-image generative AI Curriculum material (Fig. 14)

From the perspective of learning and motivation, the need to design practices and technologies that promote and sustain children's curiosity and interest has been highlighted by many researchers (e.g. Blumenfeld *et al.*, 1991; Hakkarainen and Seitamaa-Hakkarainen, 2022; Resnick, 2006). In line with knowledge-creative and design-oriented pedagogies, the aim in the first workshop was to connect students' interests through classroom discourses and materials that prompted students to reflect on and share their everyday experiences and thus see the relevance of developing an understanding of ML.

Furthermore, the open-ended learning tasks of co-designing their own apps enabled the children to define their own goals and ideas for classifiers. In this sense, the open-ended design task deliberately scaffolded students to connect and share their interests, prior experiences, and knowledge, which, in turn, can enhance students' intrinsic motivation (Kim *et al.*, 2018). In addition, the children were able to personalize their projects and had the agency to affect their courses of action. As highlighted by Roth and Lee (2006), the expansion of action possibilities with respect to meaningful problems and activities is intricately intertwined with children's agency and ownership of learning.

Moreover, the distributed scaffolding system aimed at providing a powerful and generative route for exploring some key concepts in computer science in a highly meaningful, engaging, and contextualized fashion (e.g. Blikstein and Worsley, 2016; Kafai *et al.*, 2018; Resnick, 2017). With the help of educational technology, the children were guided to explore the meaning of key concepts related to classifiers, as well as to follow the basic epistemic functions related to ML project workflows. In this manner, learning new conceptual knowledge was applied in design practice, and the affordances were structured in a way that assisted in directing invention activities further by gradually unveiling new concepts and the required steps. In these tool-mediated activities, the teams were also facilitated in constructing and reconstructing their understanding by testing their classifiers and analyzing the results (cf. Puntambekar and Kolodner, 2005). Through this approach, the dynamic tool became a vehicle for prompting students' conjectures about the behavior of the classifier, and this helped them to refine their designs and conceptions to come up with better solutions.

However, with an easy-to-use tool, children can quickly build their own classifiers, but this does not guarantee that students are building their understanding of the disciplinary concepts and practices. While technologies may complement and assist teachers' work and scaffolding, the tool itself does not diagnose students' state of understanding or motivation. Thus, it would be an oversimplification to consider how educational technology on its own can scaffold children's learning without considering the other aspects of distributed scaffolding systems (Quintana *et al.*, 2004) aimed at supporting particular social practices and pedagogical models (Pea, 2004).

Consequently, these tool-mediated activities need to be augmented with additional support. In this project, learning conceptual knowledge was scaffolded through question prompts that asked students to externalize their thinking and share their thoughts and ideas with others during the evolving process of learning and design. In line with the knowledge-creative approach, the children were guided to work in teams in which they were jointly creating, making, reflecting, and advancing their ideas and solutions (Hakkarainen and Seitamaa-Hakkarainen, 2022). These collaborative activities and discourses were mediated and supported by the learning tool and related materials in different phases of the project: when exploring ML-based educational technologies in the first workshop, when creating datasets and testing their own applications in the second workshop, and when sharing the co-designed apps in the final workshop. In this sense, key concepts were explored in and through various collaborative activities and mediational means in the evolving process of co-design.

Yet, it was also observed that students needed teachers' support in connecting ML to their interests and everyday experiences as well as when defining their joint app ideas and carrying out the joint activities. In particular, teachers' support was needed to engage teams in the kinds of reasoning processes that would afford connections between their designs and the disciplinary concepts they were learning and explaining (see Puntambekar and Kolodner, 2005). Even though such lines of reasoning were explicitly mediated by the tool and related curriculum materials, it appeared that teachers' support was needed in guiding students to take more advantage of the afforded resources. As noted by Martin *et al.* (2019), tools and curriculum materials can support students' learning, but they often cannot stand alone, because they often provide a fixed set of prompts and thus are not adaptive to students with different needs and ZPDs. Accordingly, teachers hold a pivotal position in dynamically expanding and contextualizing the support ingrained within instructional materials (Martin *et al.*, 2019). Here, the responsive support from teachers was organized around the children's own ideas and designs and thus positioned the children as active participants in these interactions and dialogic discussions. Such dialogic interactions also enabled the teachers to ask contextual questions, monitor progress, and provide tailored support (Eshach *et al.*, 2011; Van de Pol *et al.*, 2010; Wood *et al.*, 1976). Accordingly, teachers played a vital role in scaffolding the students' learning and co-design processes (Puntambekar and Kolodner, 2005; Viilo, 2020), and the quality of this responsive scaffolding was key to students' learning (Martin *et al.*, 2019).

Additionally, an increased understanding of ML, together with data-driven design, also facilitated children in engaging in critical reflections and discussions on the societal and ethical implications of AI in the final workshop. The children were guided to reflect on the potential risks and harms of AI through their own designs, as well as by exploring the concepts of algorithmic bias through the use of generative AI. Accordingly, there was a deliberate attempt to contextualize AI ethics in the children's own ideas and everyday lives in a manner that could promote more critical attitudes toward the technologies and power structures that shape everyday lives, such as those behind popular social me-

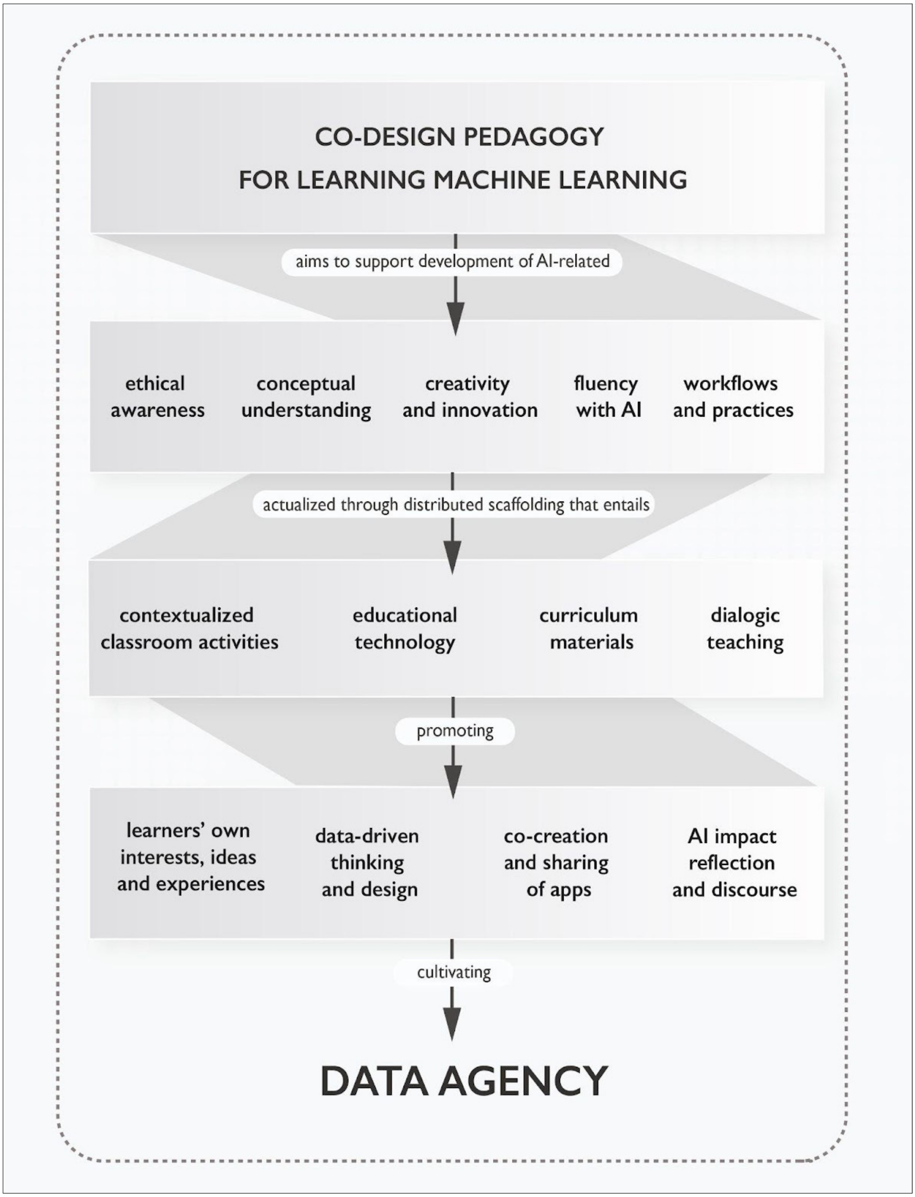

Fig. 16. Components of co-design pedagogy to foster children's data agency and creative abilities in the age of AI.

dia platforms discussed in the first workshop. Notably, particular attention was paid to building thematic continuity (Tabak, 2004) between the workshops instead of teaching isolated content units.

In summary, the students were offered a large degree of freedom in terms of what to co-design within the epistemic, material, and social structures aimed at supporting the learning of basic ML concepts and practices. Yet, a lot of co-design and pre-planning was done in order to orchestrate relations among the subjects, tools, materials, and supportive learning technologies that mediated the object-oriented activities (Hämäläinen and Vähäsantanen, 2011; Littleton *et al.*, 2012). Students' learning and understanding were scaffolded through a variety of sources, including curriculum materials, tools, peer discussions, and teacher facilitation. Fig. 16 presents the key components of co-design pedagogy employed in the intervention. As argued by Tabak (2004), if teachers, materials, software, and peer scaffolding work in "synergy," it also increases the likelihood that students will learn to use new concepts and tools in culturally appropriate ways. Moreover, if new conceptual knowledge and practices are learned by being discussed, explored, and applied in a variety of situations, they may also facilitate the creation of a rich web of memorable associations between them and the problem-solving contexts at hand (Collins *et al.*, 1989; Krajcik and Blumenfeld, 2006).

8. Conclusions and Future Work

To conclude, this study illustrates how co-design between researchers and teachers is crucial for developing novel learning environments and practices for learning ML. These joint efforts also provided indirect scaffolding for the emerging learning activities of the students, as the focus of the co-design was on the specification of the objectives and learning tasks that pupils pursued and the development of appropriate educational technologies and curriculum materials for scaffolding the different stages of action. Overall, the design of novel educational practices that were simultaneously relevant, appropriate, and capable of being realized was crucially dependent on capitalizing on complementary expertise. It is evident that the multifaceted outcomes of this co-design and development effort could not have been accomplished by any single researcher or teacher alone. Rather, this development work involved 1) the director of the city's education authority and the director of the city's media center, with their extensive experience in organizing collaborations with schools and universities in various research and development projects; 2) teachers and school principals from 12 schools who provided their unique insights with regard to adapting and developing the practices and educational technologies to serve their local contexts and the actual needs of their own students; 3) educational researchers who brought theoretical and pedagogical ideas from the learning of science and experience from classroom teaching; 4) researchers from the field of computer science who contributed their extensive experience in computational thinking and ML educational tools, and who possessed the programming expertise necessary to translate the pedagogical intentions into innovative educational technology; and 5) two research assistants who provided crucial support for various project implementation tasks.

As an outcome of such cross-boundary collaboration, concrete resources, tools, and a pedagogical model to orchestrate ML projects in K-9 education were developed. Although some teachers might possess knowledge about AI, especially domain-specific support was built into the distributed scaffoldings to help the work of teachers who were not domain experts themselves. Thus, the structure of the tool and the guiding questions in the curriculum materials were also intended to communicate to the teacher the key concepts and procedures that should be marked in their interactions with student teams. Teachers can also use curriculum materials for ongoing diagnoses and to keep track of the group's progress over a period of time (Puntambekar and Hubscher, 2002). Through this approach, both the student teams and teachers can see the progress that is being made during the project activities (Belland *et al.*, 2013). These guides and materials are not intended to serve as rigid scripts to follow, but as pedagogical principles and suggestions for implementing creative AI projects. They are designed to support teachers to plan and contextualize the core ideas to fit their unique classroom settings and needs of their students. We are in the process of developing additional teacher materials that include short videos, presentation slides sets, and materials that teachers can apply, edit and modify to accommodate their own educational needs.

Yet, the orchestration of distributed scaffolding in context-bound activities is challenging, as it always relates to the theoretical core of scaffolding – the idea of the ZPD, as Belland (2014) has pointed out. Scaffolding strategies for middle-school students and the scaffolding of younger or older children will differ, as these learners have different needs and are at different developmental levels (Belland, 2014; Pea, 2004). As the research program moves forward, there is evidently a need to better understand how to contextualize the curriculum to meet the needs of different groups of students. Likewise, there is a need to study how these various scaffolds embedded in different stages of the program actually support learning and understanding to evaluate what is missing in the current forms of scaffolding. While the analysis of the written reasoning test, which was administered prior to and after the intervention, showed statistically significant progress in the children's data-driven explanations (Vartiainen *et al.*, 2024), there is a clear need to dig deeper into the process of collaborative learning and design to explore the epistemic activities that supported or hindered the development of understanding.

Moreover, there is a need to study more deeply how teachers orchestrate distributed scaffolding to enable the building of better professional development activities and scaffolding for teachers. However, previous research has also shown that reforms in educational institutions are often ineffective because they tend to focus on isolated elements while disregarding the sociocultural interplay of wider educational structures, such as national policies and curricula, and various contextual factors, such as local school practices, goals, and values, which all shape the everyday activities of teachers (Härkki *et al.*, 2021). While the present project provided promising results in terms of integrating ML topics into school education in Finland, it also illustrates how national strategies, policy making, school-level leadership, and collegial collaboration play an important role in promoting innovative and knowledge-creative relationships among teachers and researchers. Although the question remains as to how to scale up such practices and support the work of teachers in different educational settings, the description of a multilayered process of co-design, coupled with the proposed framework that integrates distributed scaffolding and agentic practices, may provide important insights for future efforts. This article was also aimed at providing analytical tools for designing, orchestrating, regulating, and reflecting on the complex interrelationships of the emerging learning systems that position children as designers and makers of AI.

As for the future, this program's collaboration with the local highly committed teachers and their students will continue. The program's aim is to co-design new tools and affordances that are responsive to children's evolving skills and understanding by increasing the complexity of AI concepts and practices. As this intervention has shown, children and young people are very active social media users at this age (Vartiainen *et al.*, 2023). We are currently co-designing educational technology and related scaffolds to demystify the mechanisms and logic of social media platforms. Our goal is to support children to understand the nature and purpose of data collection, its use in algorithmic profiling and recommendations, and to develop children's understanding of how social media platforms may impact the agency of individuals, communities, and broader society. As a long-term effect, this program will provide research-based pedagogical models, novel educational technologies, and an online learning environment in which all our project outputs will be openly available to anyone who is interested. The heart of the idea is to provide various tools and resources to scaffold the development of all children's data agency; their ability and volition to be active players and contributing members in our data-driven society.

Acknowledgments

This study received funding from the Strategic Research Council (SRC) established within the Research Council of Finland, grants #352859 and #352876. The authors thank the January Collective for their continuous support.

References

Belland, B.R. (2014). Scaffolding: Definition, Current Debates, and Future Directions. In: M. D. and E. J. and B.M.J. Spector J. Michael and Merrill (Ed.), *Handbook of Research on Educational Communications and Technology* (pp. 505–518). Springer New York. https://doi.org/10.1007/978-1-4614-3185-5_39

Belland, B.R., Kim, C., Hannafin, M.J. (2013). A Framework for Designing Scaffolds That Improve Motivation and Cognition. *Educational Psychologist*, 48(4), 243–270. https://doi.org/10.1080/00461520.2013.838920

Blikstein, P., Worsley, M. (2016). Children Are Not Hackers: Building a Culture of Powerful Ideas, Deep Learning, and Equity in the Maker Movement. In: K. Peppler, E. Halverson, Y.B. Kafai (Eds.), *Makeology* (pp. 64–79). Routledge.

Blumenfeld, P.C., Soloway, E., Marx, R.W., Krajcik, J.S., Guzdial, M., Palincsar, A. (1991). Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educational Psychologist*, 26(3–4), 369–398. https://doi.org/10.1080/00461520.1991.9653139

Brown, J.S., Collins, A., Duguid, P. (1989). Situated Cognition and the Culture of Learning. *Educational Researcher*, 18(1), 32. https://doi.org/10.2307/1176008

Calor, S.M., Dekker, R., van Drie, J.P., Volman, M.L.L. (2022). Scaffolding small groups at the group level: Improving the scaffolding behavior of mathematics teachers during mathematical discussions. *Journal of the Learning Sciences*, 31(3). https://doi.org/10.1080/10508406.2021.2024834

Ching, C.C., Kafai, Y.B. (2008). Peer Pedagogy: Student Collaboration and Reflection in a Learning-Through-Design Project. *Teachers College Record*, 110(12), 2601–2632. https://doi.org/10.1177/016146810811001203

Cole, M., Engeström, Y. (1993). A cultural-historical approach to distributed cognition. In: G. Salomon (Ed.), *Distributed Cognitions: Psychological and Educational Considerations* (pp. 1–46).

Collins, A., Brown, J.S., Newman, S.E. (1989). Cognitive apprenticeship: teaching the crafts of reading, writing, and mathematics. In: Resnick L.B. (Ed.), *Knowing, Learning and Instruction: Essays in Honor of Robert Glaser* (pp. 453–494). Hillsdale, NJ: Erlbaum.

Cui, Y., Chen, F., Lutsyk, A., Leighton, J.P., Cutumisu, M. (2023). Data literacy assessments: A systematic literature review. *Assessment in Education: Principles, Policy & Practice*, 30(1), 76–96. https://doi.org/10.1080/0969594X.2023.2182737

Damşa, C.I., Kirschner, P.A., Andriessen, J.E.B., Erkens, G., Sins, P.H.M. (2010). Shared epistemic agency: An empirical study of an emergent construct. *Journal of the Learning Sciences*, 19(2), 143–186. https://doi.org/10.1080/10508401003708381

Denning, P.J., Tedre, M. (2019). *Computational Thinking*. Cambridge, MA: MIT Press.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher,* 32(1), 5–8.

Edwards, A. (2007). An Interesting Resemblance: Vygotsky, Mead and American Pragmatism. In: H. Daniels, M. Cole, Wertsch. J.V. (Eds.) *The Cambridge Companion to Vygotsky* (pp. 77–100). Cambridge: Cambridge University Press.

Engeström, Y. (1987). *Learning by Expanding: An Activity-theoretical Approach to Developmental Research*. Helsinki: Orienta-Konsultit.

Eshach, H., Dor-Ziderman, Y., Arbel, Y. (2011). Scaffolding the "Scaffolding" Metaphor: From Inspiration to a Practical Tool for Kindergarten Teachers. *J Sci Educ Technol* 20, 550–565. https://doi.org/10.1007/s10956-011-9323-2

Fischer, G., Giaccardi, E., Ye, Y., Sutcliffe, A.G., Mehandjiev, N. (2004). Meta-design: A manifesto for end-user development. *Communications of the ACM*, 47(9), 33–37. https://doi.org/10.1145/1015864.1015884

Guzdial, M. (1995). Software-realized scaffolding to facilitate programming for science learning. *Interactive Learning Environments*, 4(1). Pp. 1–44.

Hakkarainen, K., Paavola, S., Kangas, K., Seitamaa-Hakkarainen, P. (2013). Socio-cultural perspectives on collaborative learning: Towards collaborative knowledge creation. In: C. Hmelo-Silver, C. Chinn, C. Chan, A. O'Donnell (Eds.), *The International Handbook of Collaborative Learning* (pp. 57–73). https://doi.org/10.1017/CBO9781107415324.004

Hakkarainen, K., Seitamaa-Hakkarainen, P. (2022). Learning by inventing: Theoretical foundations. In: T. Korhonen, K. Kangas, L. Salo (Eds.), *Invention Pedagogy: The Finnish Approach to Maker Education* (pp. 15–27). Routledge.

Harel, I. (1991). *Children Designers*. Norwood, NJ: Ablex.

Heinemann, B., Opel, S., Budde, L., Schulte, C., Frischemeier, D., Biehler, R., Podworny, S., and Wassong, T. (2018). Drafting a data science curriculum for secondary schools. In: *Proceedings of the 18th Koli Calling International Conference on Computing Education Research*, Koli Calling '18, New York, NY, USA. ACM. https://doi.org/10.1145/3279720.3279737

Heintz, F., Roos, T. (2021). Elements of AI – teaching the basics of AI to everyone in Sweden. In: *Proceedings of the 13th International Conference on Education and New Learning Technologies (EDULEARN21)*, pages 2568–2572, Online. IATED.

Hendricks, VF., Vestergaard, M. (2018). *Reality Lost: Markets of Attention, Misinformation and Manipulation*. DOI: 10.1007/978-3-030-00813-0.

Hennessy, S. (2011). The role of digital artefacts on the interactive whiteboard in supporting classroom dialogue. *Journal of Computer Assisted Learning*, 27(6), 463–489. https://doi.org/10.1111/j.1365-2729.2011.00416.x

Hennessy, S., Murphy, P. (1999). The potential for collaborative problem solving in design and technology. *International Journal of Technology and Design Education*, 9(1), 1–36. https://doi.org/10.1023/A:1008855526312

Hintz, A., Dencik, L., Wahl-Jorgensen, K. (2019). *Digital Citizenship in a Datafied Society*. Cambridge, UK: Polity Press.

Hämäläinen, R., Vähäsantanen, K. (2011). Theoretical and pedagogical perspectives on orchestrating creativity and collaborative learning. *Educational Research Review*, 6(3), 169–184. https://doi.org/https://doi.org/10.1016/j.edurev.2011.08.001

Härkki, T., Vartiainen, H., Seitamaa-Hakkarainen, P., Hakkarainen, K. (2020). Co-teaching in non-linear projects: A contextualised model of co-teaching to support educational change. *Teaching and Teacher Education,* 97(2021).

Höper, L. (2021). Developing and evaluating the concept data awareness for K12 computing education. In: *Proceedings of the 21st Koli Calling International Conference on Computing Education Research (Koli Calling '21)*. ACM, New York, NY, USA, Article 41, 1–3. https://doi.org/10.1145/3488042.3490509

Jonassen, D. H., Rohrer-Murphy, L. Activity theory as a framework for designing constructivist learning environments. *ETR&D* 47, 61–79 (1999). https://doi.org/10.1007/BF02299477

Kafai, Y.B., Fields, D.A., Searle, K.A. (2018). Understanding Media Literacy and DIY Creativity in Youth Digital Productions. In: *The International Encyclopedia of Media Literacy*. https://doi.org/10.1002/9781118978238.ieml0058

Kafai, Y. B., Proctor, C. (2021). A Revaluation of Computational Thinking in K–12 Education: Moving Toward Computational Literacies. *Educational Researcher*, 51(2), 146–151. https://doi.org/10.3102/0013189X211057904

Kaptelinin, V., Nardi, B. (2012). Activity theory in HCI: Fundamentals and reflections. In: *Synthesis Lectures on Human-centered Informatics*. Morgan & Claypool.

Kitchin, R. (2012). *The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences*. London, UK: Sage. DOI: 10.1108/oir-01-2015-0011.

Kim, M.C., Hannafin, M.J. (2011). Scaffolding problem solving in technology-enhanced learning environments (TELEs): Bridging research and theory with practice. *Computers and Education*, 56(2). https://doi.org/10.1016/j.compedu.2010.08.024

Kim, N.J., Belland, B.R., Axelrod, D. (2019). Scaffolding for optimal challenge in k–12 problem-based learning. *Interdisciplinary Journal of Problem-Based Learning*, 13(1). https://doi.org/10.7771/1541-5015.1712

Kodoner, J. (2002). Facilitating the learning of design practices.: Lesson learned from an inquiry in science education. *Journal of Industrial Teacher Education*, 39(3), 1–31.

Kozulin, A., Gindis, B., Ageyev, V.S., Miller, S.M. (2003). Introduction: Sociocultural Theory and Education: Students, Teachers, and Knowledge. In: A. Kozulin, B. Gindis, V.S. Ageyev, S.M. Miller (Eds.), *Vygotsky's Educational Theory in Cultural Context* (pp. 1–14). Cambridge University Press.

Krajcik, J.S., Blumenfeld, P.C. (2006). Project-based learning. In: *The Cambridge Handbook of the Learning Sciences* (pp. 317–333). Cambridge University Press.

Kramer, A.D.I., Guillory, J.E., Hancock J.T. (2014). Experimental evidence of massive-scale emotional contagion through social networks. *Proceedings of the National Academy of Sciences of the United States of America,* 111(24): 8788–8790. DOI: 10.1073/pnas.1320040111.

Lim, J., Leinonen, T., Lipponen, L., Lee, H., DeVita, J., Murray, D. (2023). Artificial intelligence as relational artifacts in creative learning. *Digital Creativity*, 34(3):192–210. DOI: 10.1080/14626268.2023.2236595

Littleton, K., Scanlon, E., Sharples, M. (2012). Editorial introduction: Orchestrating inquiry learning. In K. Littleton, E. Scanlon, M. Sharples (Eds.), *Orchestrating Inquiry Learning* (pp. 1–6). Routledge. https://doi.org/10.4324/9780203136195-6

Long, D., Magerko, B. (2020, April). What is AI literacy? Competencies and design considerations. In: *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1–16). https://doi.org/10.1145/3313831.3376727

Niemi, H., Lavonen, J. (2020). Teacher Education in Finland: Persistent Efforts for High-Quality Teachers. In: L. Lefty J.W. Fraser (Eds.), *Teaching the World's Teachers* (pp. 153–178). Johns Hopkins University Press.

Niemi, H., Toom, A., Kallioniemi, A., Lavonen, J. (2018). Teaching profession amid changes in the educational ecosystems. In: A. Toom A. Kallioniemi (Eds.), *The Teacher's Role in the Changing Globalizing World: Resources and Challenges Related to the Professional Work of Teaching* (pp. 141–149) [EBSCOhost Ebook Academic Collection – WorldWide]. Leiden, The Netherlands: Brill. https://doi.org/10.1163/9789004372573

Marques, L.S., Gresse von Wangenheim, C., Hauck, J.C. (2020). Teaching machine learning in school: A systematic mapping of the state of the art. *Informatics in Education*, 19(2), 283–321.

Martin, N.D., Dornfeld Tissenbaum, C., Gnesdilow, D., Puntambekar, S. (2019). Fading distributed scaffolds: the importance of complementarity between teacher and material scaffolds. *Instr Sci*, 47, 69–98. https://doi.org/10.1007/s11251-018-9474-0

Paavola, S., Hakkarainen, K. (2005). The knowledge creation metaphor – An emergent epistemological approach to learning. *Science & Education*, 14, 535–55.

Palsa, L., Mertala, P. (2023). Contextualizing everyday data literacies: The case of recreational runners. *International Journal of Human–Computer Interaction*, 1–12. https://doi.org/10.1080/10447318.2023.2241612

Pangrazio, L., Selwyn, N. (2019). 'Personal data literacies': A critical literacies approach to enhancing understandings of personal digital data. *New media & society*, 21(2), 419–437. DOI: 10.1177/1461444818799523.
Papert, S. (1980). *Mindstorms: Children, computers, and Powerful Ideas*. New York: Basic Books, Inc.
Pea, R.D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *Journal of the Learning Sciences*, 13(3). https://doi.org/10.1207/s15327809jls1303_6
Penuel, W.R., Fishman, B.J., Haugan Cheng, B., Sabelli, N. (2011). Organizing Research and Development at the Intersection of Learning, Implementation, and Design. *Educational Researcher*, 40(7), 331–337. https://doi.org/10.3102/0013189X11421826
Pope, N., Kahila, J., Vartiainen, H., Tedre, M. Children's AI Design Platform for Making and Deploying ML-Driven Apps. *TechRxiv.*
Puntambekar, S., Hubscher, R. (2002). Scaffolding in complex learning environments: What we have gained and what we have missed. *Educational Psychologist*, 40, 1–12.
Puntambekar, S., Hübscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, 40(1). https://doi.org/10.1207/s15326985ep4001_1
Puntambekar, S., Kolodner, J.L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. *J. Res. Sci. Teach*., 42: 185–217. https://doi.org/10.1002/tea.20048
Quintana, C., Reiser, B.J., Davis, E.A., Krajcik, J., Fretz, E., Duncan, R.G., Kyza, E., Edelson, D., Soloway, E. (2004). A Scaffolding Design Framework for Software to Support Science Inquiry. *Journal of the Learning Sciences*, 13(3), 337–386. https://doi.org/10.1207/s15327809jls1303_4
Rahwan, I., Cebrian, M., Obradovich, N., Bongard, J., Bonnefon, J.F., Breazeal, C., Crandall, J.W., Christakis, N.A., Couzin, I.D., Jackson, M.O., Jennings, N.R., Kamar, E., Kloumann, I. M., Larochelle, H., Lazer, D., McElreath, R., Mislove, A., Parkes, D.C., Pentland, A. 'Sandy,' … Wellman, M. (2019). Machine behaviour. Nature, 568(7753), 477–486. https://doi.org/10.1038/s41586-019-1138-y
Reeves, T. (2006). Design research from a technology perspective. In J. van den Akker, K. Gravemeijer, S. McKenney, N. Nieveen (Eds.), *Educational design research* (pp. 52–66). London: Routledge.
Resnick, M. (2006). Computer as Paintbrush: Technology, Play, and the Creative Society. In: D. Singer, R. Golikoff, K. Hirsh-Pasek (Eds.), *Play = Learning: How Play Motivates and Enhances Children's Cognitive and Social-Emotional Growth*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195304381.003.0010
Resnick, M. (2017). *Lifelong Kindergarten: Cultivate Creativity Through Projects, Passion, Peers, and Play*. MIT Press.
Resnick, M., Silverman, B. (2005). Some Reflections on Designing Construction Kits for Kids. In: *Proceedings of the 2005 Conference on Interaction Design and Children*, 117–122. https://doi.org/10.1145/1109540.1109556
Rizvi, S., Waite, J., Sentance, S. (2023). Artificial Intelligence teaching and learning in K-12 from 2019 to 2022: A systematic literature review. *Computers and Education: Artificial Intelligence*, 100145. https://doi.org/10.1016/j.caeai.2023.100145
Rogoff, B., Mistry, J., Göncü, A., Mosier, C., Chavajay, P., Heath, S.B., Goncu, A. (1993). Guided Participation in Cultural Activity by Toddlers and Caregivers. *Monographs of the Society for Research in Child Development*, 58(8), i. https://doi.org/10.2307/1166109
Roth, W.-M. (1998). *Designing Communities*. Dordrecht: Kluwer Academic.
Roth, W.M., Lee, Y.J. (2006). Contradictions in theorizing and implementing communities in education. *Educational Research Review*, 1(1), 27–40. https://doi.org/10.1016/j.edurev.2006.01.002
Sanusi, I.T., Oyelere, S.S., Vartiainen, H., Suhonen, J., Tukiainen, M. (2023). A systematic review of teaching and learning machine learning in K-12 education. *Education and Information Technologies*, 28(5), 5967–5997. https://doi.org/10.1007/s10639-022-11416-7
Seitamaa-Hakkarainen, P., Kangas, K., Raunio, A.-M., Hakkarainen, K. (2012). Collaborative design practices in technology mediated learning. *Journal of Design and Technology Education*, 17(1), 54–65.
Seitamaa-Hakkarainen, P., Sormunen, K., Davies, S., Matilainen, J., Hakkarainen, K. (2022). Collaboration and co-regulation in Invention Projects. In: T. Korhonen, K. Kangas, L. Salo (Eds.), *Invention Pedagogy: The Finnish Approach to Maker Education* (pp. 40–55). Routledge.
Sormunen, K., Viilo, M. (2022). Orchestrating invention activities through teacher's multilayered work. In: T. Korhonen, K. Kangas, L. Salo (Eds.), *Invention Pedagogy: The Finnish Approach to Maker Education* (pp. 132–147). Routledge.
Scardamalia, M., Bereiter, C. (1993). Computer Support for Knowledge-Building Communities. *The Journal of the Learning Sciences*, 3(3), 265–283. http://www.jstor.org/stable/1466822

Schoultz, J., Säljö, R., Wyndhamn, J. (2001). Heavenly talk: Discourse, artifacts, and children's understanding of elementary astronomy. *Human Development,* 44(2–3), 103–118.

Sfard, A. (1998). On two metaphors for learning and the danger of choosing just one. *Educational Researcher,* 27(2), 4–13.

Shapiro, R.B., Fiebrink, R., Norvig, P. (2018). How machine learning impacts the undergraduate computing curriculum. *Communications of the ACM*, 61(11), 27–29

Shapiro, R.B., Fiebrink, R. (2019). Introduction to the special section: Launching an agenda for research on learning machine learning. *ACM Transactions on Computing Education (TOCE)*, 19(4), 1–6.

Shelby, R., Rismani, S., Henne, K., Moon, A., Rostamzadeh, N., Nicholas, P., ... & Virk, G. (2023, August). Sociotechnical harms of algorithmic systems: Scoping a taxonomy for harm reduction. In: *Proceedings of the 2023 AAAI/ACM Conference on AI, Ethics, and Society* (pp. 723–741).

Tabak, I. (2004). Synergy: A complement to emerging patterns of distributed scaffolding. *Journal of the Learning Sciences*, 13(3). `https://doi.org/10.1207/s15327809jls1303_3`

Tabak, I., Kyza, E.A. (2018). Research on scaffolding in the learning sciences: A methodological perspective. In: *International Handbook of the Learning Sciences* (pp. 191–200). Taylor and Francis. `https://doi.org/10.4324/9781315617572`

Tedre, M, Vartiainen, H, Kahila, J, *et al.* (2020). Machine learning introduces new perspectives to data agency in K-12 computing education. In: *Proceedings of the Frontiers in Education Conference (FIE), Uppsala, 21–24 October*. New York: IEEE.

Tedre, M., Toivonen, T., Kahila, J., Vartiainen, H., Valtonen, T., Jormanainen, I., Pears, A. (2021). Teaching machine learning in K-12 Classroom: Pedagogical and technological trajectories for artificial intelligence education. *IEEE Access*, 9, 110558–110572. `https://doi.org/10.1109/ACCESS.2021.3097962`

Tenório, K., Olari, V., Chikobava, M., Romeike, R. (2023, March). Artificial Intelligence Literacy Research Field: A Bibliometric Analysis from 1989 to 2021. In: *Proceedings of the 54th ACM Technical Symposium on Computer Science Education V. 1* (pp. 1083–1089). `https://doi.org/10.1145/3545945.3569874`

Toivonen, T., Jormanainen, I., Kahila, J., Tedre, M., Valtonen, T., Vartiainen, H. (2020). Co-designing machine learning apps in K–12 with primary school children. In: *2020 IEEE 20th International Conference on Advanced Learning Technologies (ICALT)* (pp. 308–310). IEEE.

Touretzky, D., Gardner-McCune, C., Martin, F., Seehorn, D. (2019, July). Envisioning AI for K-12: What should every child know about AI?. In: *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 33, No. 01, pp. 9795–9799).

UNESCO (2022). *K-12 AI Curricula: A Mapping of Government-endorsed AI Curricula*. UNESCO, Paris. `https://unesdoc.unesco.org/ark:/48223/pf0000380602`

Van de Pol, J., Volman, M., Beishuizen, J. (2010). Scaffolding in teacher-student interaction: A decade of research. *Educational Psychology Review*, 22(3). `https://doi.org/10.1007/s10648-010-9127-6`

Valtonen, T, Tedre, M, Mäkitalo, K, *et al.* (2019). Media Literacy Education in the Age of Machine Learning. *Journal of Media Literacy Education* 11(2). DOI: 10.23860/jmle-2019-11-2-2.

Vartiainen, H., Tedre, M., Valtonen, T. (2020). Learning machine learning with very young children: Who is teaching whom?. *International Journal of Child-computer Interaction*, 25, 100182.

Vartiainen, H., Toivonen, T., Jormanainen, I., Kahila, J., Tedre, M., Valtonen, T. (2021). Machine learning for middle schoolers: Learning through data-driven design. *International Journal of Child-Computer Interaction*, (29). `https://doi.org/10.1016/j.ijcci.2021.100281`

Vartiainen, H., Pellas, L., Kahila, J., Valtonen, T., Tedre, M. (2022). Pre-service teachers' insights on data agency. *New Media & Society*, 14614448221079626. `https://doi.org/10.1177/14614448221079626`

Vartiainen, H. (2022). Cross-boundary co-design for learning machine learning. *AI, Data Science, and Young People. Understanding Computing Education*.

Vartiainen, H., Kahila, J., Tedre, M., Sointu, E., Valtonen, T. (2023). More than fabricated news reports: Children's perspectives and experiences of fake news. *Journal of Media Literacy Education*, 15(2), 17–30. `https://doi.org/10.23860/JMLE-2023-15-2-2`

Vartiainen, H., Tedre, M., Jormanainen, I. (2023). Co-creating digital art with generative AI in K-9 education: Socio-material insights. *International Journal of Education Through Art (IJETA)*, 19(3), 405–423.

Vartiainen, H., Kahila, J., Tedre, M., López-Pernas, S., & Pope, N. (2024). Enhancing children's understanding of algorithmic biases in and with text-to-image generative AI. New Media & Society, 0(0). `https://doi.org/10.1177/14614448241252820`

Viilo, M. (2020). *Teacher's Orchestration in Longitudinal Collaborative Inquiry Process*. Helsinki Studies in Education, Unigrafia.

Viilo, M., Seitamaa-Hakkarainen, P., Hakkarainen, K. (2018). Teacher's long-term orchestration of technology-mediated collaborative inquiry project. *Scandinavian Journal of Educational Research*, 1–26.

Vuorikari, R., Punie, Y., Gomez, S.C., Van Den Brande, G. (2016). DigComp 2.0: The digital competence framework for citizens. Update phase 1: The conceptual reference model (No. JRC101254). Luxembourg Publication Office of the European Union.

Vygotsky, L. (1978). Mind in Society. In: *Mind in Society*. Harvard University Press. https://doi.org/10.2307/j.ctvjf9vz4

von Wangenheim, C. G., Marques, L. S., Hauck, J. C. (2020). Machine learning for all–introducing machine learning in K-12. SocArXiv. https://doi.org/10.31235/osf.io/wj5ne

Wenger, E. (1998). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge: Cambridge University Press.

Wells, G. (2007). Semiotic mediation, dialogue and the construction of knowledge. *Human Development*, 50(5), 244–274.

Wells, G., Claxton, G. (2002). Introduction: Sociocultural perspectives on the future of education. In: G. Wells, G. Claxton (Eds.), *Learning for Life in the 21st Century* (pp. 1–17). Blackwell Publishing.

Wertsch, J.V. (2007). Mediation. In: H. Daniels, M. Cole, J.V. Wertsch (Eds.), *The Cambridge Companion to Vygotsky* (pp. 178–192). https://doi.org/10.1017/CCOL0521831040

Wood, D., Bruner, J.S., Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, 17(2). https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Zhou, X., Van Brummelen, J., Lin, P. (2020). Designing AI learning experiences for K-12: Emerging works, future opportunities and a design framework. arXiv preprint arXiv:2009.10228. https://doi.org/10.48550/arXiv.2009.10228

Zuboff, S. (2015) Big other: Surveillance capitalism and the prospects of an information civilization. *Journal of Information Technology* 30(1): 75–89. DOI: 10.1057/jit.2015.5.

J. Kahila is a post-doctoral researcher at the University of Eastern Finland, School of Applied Educational Science and Teacher Education.

H. Vartiainen is a senior researcher at the University of Eastern Finland, School of Applied Educational Science and Teacher Education.

M. Tedre is a professor of computer science at University of Eastern Finland.

E. Arkko is research assistant at the University of Eastern Finland, School of Computing.

A. Lin is research assistant at the University of Eastern Finland, School of Computing.

N. Pope is a senior researcher at the University of Eastern Finland, School of Computing.

I. Jormanainen currently works as a University Lecturer and Senior Researcher with the research group of Technologies for Learning and Development at the School of Computing, University of Eastern Finland. His major research interests include AI education, educational robotics, technology education in K-12 settings, and ICT for development.

T. Valtonen is a professor of education at the University of Eastern Finland. His research interests include the use of information and communication technology in education, targeting, especially pre-service teachers' skills, and readiness to use ICT in education.