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The Impact of Digital and Analog Approaches on a Multidimensional Preschool Science Education

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Abstract
Swedish preschool science practice is confined to a unique educational setting where upbringing, care, and education are intertwined. This allows teachers to develop innovative cross-curricular and multidimensional science teaching. At the same time, society demands the digitalization of preschool practice, which has caused concern not only about negative effects on children's well-being but also the risk of foregrounding digital over analog tools in multidimensional and child-centered preschool practice. The aim of this study is to analyze how preschool teachers at the forefront of digitalization integrate digital and analog tools when teaching science and how this integration affects their practice. The data comprises documentation of digitalized science activities provided by ten preschool teachers and transcribed recall interviews with four of the teachers. Thematic content analysis and a framework for analyzing seven teaching dimensions of preschool science revealed the use of digital and analog tools as drivers for multidimensional science education. The findings show that the teachers primarily use digital tools to reinforce social learning, inclusion, and agency during science activities. Digital and analog tools were used to complement one another in pursuing the boundaries of multidimensional science. However, the content of this innovative and digitalized science teaching remained primarily within biology, the traditional scholarly discipline in preschool science. We conclude that the digitalization of preschool science seems to be used to strengthen and diversify teaching within the boundaries of overarching traditional preschool practice where nature encounters and children's interests and well-being are at the forefront.

Keywords Preschool science education · Multidimensional science · Digital and analog approaches · Digital technologies

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Introduction

Since digital technology has become part of the educational system and integrated more into society, the possibilities for learning and teaching have changed dramatically. Digital tools now provide sources of knowledge that most people outside of the research establishment did not have prior access to (Papert, 1999). Through a few clicks or taps, it is possible to find out facts such as scientific phenomena in text form, often combined with an array of visual representations. In a preschool context, digital tools have been suggested to offer additional modes to an already multidimensional preschool science (Kewalramani & Veresov, 2022; Rhoades, 2016). However, researchers and teachers also increasingly question digitalization in preschool settings. For example, contemporary research argues that using digital tools might harm children younger than two years for medical reasons (Nutley & Thorell, 2021). Others point to pedagogical concerns for avoiding digital tools in preschool teaching, such as that children's cognitive development can be negatively affected (Sundqvist et al., 2021). Researchers are also concerned about the risk of favoring digital tools over analog dimensions (e.g., Nilsen, 2018). Still, the literature provides few descriptions of how preschool teachers harness multimodality by combining digital and analog representations and their possibilities in preschool science (Kewalramani & Veresov, 2022). Teachers' perspectives also need to be highlighted. In this article, teachers' descriptions of how they use and integrate digital tools in combination with analog representations in their science education practice are explored around the question of if and how digital tools contribute to multidimensional preschool science.

Theoretical Framework

Preschool Science in a Digital Age

Several arguments have been directed to the use of digital tools to support children's meaning-making that include providing children with opportunities to "interpret situations, events, objects, or discourses, in the light of their previous knowledge and experience" (Zittoun & Brinkmann, 2012, p. 1809). A common claim for the advantages of using digital tools in preschools is that digital tools can offer an intuitive touch-based design that involves various modes of communicating information (Kress, 2003). Hence, digital tools do not rely on formal reading and writing abilities that young children have not yet learned to master (Kjällander & Moinian, 2014). Digital tablets have been especially shown to drive digitalization in Swedish preschools where this study is performed. The availability of digital tablets in Swedish preschools has increased significantly since municipalities made their first acquisitions in 2011–2012 (Nilsen, 2018). In parallel with the rapid advent of digital tablets, Kjällander (2016) argues that digitalization was taken seriously in preschool contexts as the desktop computer never fully fitted a preschool setting. This view is supported by results from questionnaire results where 327 preschool teachers across the whole country described tablets as common within practice. They portrayed the tablets as convenient to use and also implied that they supported children's agency as they were intuitive, multimodal touch-based designs that invite the children to take an active role in educational contexts (Otterborn et al., 2019).

Combining digital and analog tools has been touted as an example of creating multimodal learning opportunities (Kress, 2003; Yelland, 2018). Here, digital tools "are viewed as being complementary to other resources, rather than alternatives, or in competition with traditional modalities" (Yelland, 2018, p. 847). The multimodal features of digital and analog applications may be of specific interest to promoting a so-called multidimensional preschool science (e.g., Areljung & Sundberg, 2018; Kewalramani & Veresov, 2022; Rhoades, 2016; Siry, 2014). In Sweden, which is the context of the current study, preschools have had a long tradition of pursuing such multidimensional teaching where care, upbringing, play, and a holistic view of learning are combined to focus on children's confidence in their learning (Mosvold & Alvestad, 2011). In a recent study, six different dimensions of children's lives that preschool teachers intertwined during science teaching were identified: Fantasy and play, Empathy, Aesthetic modes of expression, Storytelling, Embodiment and sensory experiences, and Systematic inquiry (Areljung & Sundberg, 2018). Today however, little is known about how preschool teachers' digital approaches within preschool science education might impact the multidimensional qualities of preschool science education (Kewalramani & Veresov, 2022). Some general concerns have nevertheless been raised about how unpredictable the outcome can be when replacing analog tools with digital tools (Nilsen, 2018; Nilsen et al., 2021). Others have highlighted that dimensions such as pretend and fantasy play decrease when children use digital tablets (Samuelsson et al., 2022).

The literature also points out other various potential drawbacks to implementation of digital technology in educational contexts. For example, the often already economy-driven tech industry is gaining increasing power over policy issues (Selwyn, 2016; Williamson, 2016). Williamson (2016) also warns against monitoring preschool children through various apps where personal data is stored. Selwyn (2016) highlights the danger of teachers believing that digital technologies should solve all educational problems. In addition, there are concerns that mindful engagement is compromised when using digital tools, as these are associated with rapid and sometimes careless explorations combined with "too much" simultaneous information (Sakr, 2019). Related to this, Kjällander (2019) describes how some children find it challenging to concentrate using digital tools with many diverting modes, such as tablets.

The Teachers' Role

Teaching science in preschool requires preschool teachers that are confident and competent in science teaching. Several studies have shown that adult guidance is a cornerstone of children's development of scientific process skills and science content learning (e.g., Fleer, 2009a; Inan & Lowther, 2010; Nayfeld et al., 2011). For example, Fleer (2009a, 2009b, 2019) emphasizes the importance of teacher-supported learning (through adult mediation) in play-based contexts to promote children's self-reliance and understanding of natural science phenomena. In this way, everyday scientific concepts are connected, and children's spontaneous discoveries, collective imagining and wondering, interests, experiences, and questions are uplifted. In connection with such approaches, Johnston (2014) talks about emergent science, where children construct their understanding through play and elaboration. Here, children promote their scientific skills, attitudes, understandings, and language through shared investigations with their peers and teachers (Johnston, 2008; Larsson, 2013). At the same time, studies also report that preschool teachers have limited science knowledge, which can negatively influence the quality of science teaching in preschools (Barenthien et al., 2020; Gerde et al., 2018). The structure of, and epistemological beliefs within, preschool communities can also play a significant role in how science is afforded for the children. For example, preschool teachers' concerns about "becoming like school" may manifest in abandoning planned science activities or compulsory attendance, which is seen as something negative and will restrict children's freedom and creativity (Sundberg et al., 2018). Now that digitalization of preschool practice has become mandatory in Swedish curricula, preschool teachers need to learn to handle digital tools specifically in connection with science teaching (Walan & Enochsson, 2022). Nevertheless, many teachers feel insecure about digitalization and request clearer directives and in-service training (Otterborn et al., 2019; Marklund, 2022).

The Swedish Preschool Context

In Sweden, municipalities are responsible for providing childcare, and preschool teachers (3.5 years of university education) and childminders (no university education required) work in teams where preschool teachers are mainly responsible for how teaching is conducted (Skolverket, 2014). In Sweden, 85% of all 1–5-year-olds attend preschool (Swedish National Agency for Education, 2022). In the autumn of the year, most children turn 6 and switch to the next level of schooling. The pedagogical culture in Swedish preschool usually focuses on several subjects at a time, where it is common to integrate different themes and projects. Therefore, many curriculum areas are often dealt with simultaneously (Pramling, Samuelsson & Sheridan, 2006). In this way, subjects such as science and technology merge and intertwine (Otterborn et al., 2019; Swedish Schools Inspectorate, 2017). In 2010, the Swedish preschool curriculum was revised to strengthen learning goals in science, Swedish, mathematics, and technology. The revision meant expanding the former emphasis on biological and environmental issues to include children's understanding of chemistry and physics. However, recent literature shows that a focus on biology and nature experiences, such as regular forest excursions, still has a paramount position in Swedish preschool science activities. In addition, activities with specific learning objectives are mainly designed to emphasize caring and nurturing, while learning specific content is diminished (Sundberg et al., 2018; Westman & Bergmark, 2014). This general approach is referred to as educare in Swedish preschool practice (Swedish Schools Inspectorate, 2017).

A Multidimensional Framework for Considering Preschool Science in a Digital Age

To explore the impact of digitalization on multidimensional preschool science, we adopt the previously described six dimensions of multidimensional preschool science as a framework for analyzing the impact of digital approaches. In this regard, we were inspired by a previous study where these six dimensions were used as an analytical framework to explore how preschool teachers' multidimensional interpretations of science also contributed to education for sustainability in preschools (Sundberg et al., 2019). Theoretically speaking, that study and this study are underpinned by a socio-cultural perspective, where practices are viewed as situated in historical and cultural contexts that provide them with structure and meaning (Engeström, 1987; Lave & Wenger, 1991). Accordingly, culturally and historically formed languages, tools, documents, perceptions, symbols, roles, and rules implicitly or explicitly shape every practice. In the case of preschool science, the six dimensions intertwine in science educational practices and are thus reflections of how the teachers have adjusted their teaching to fit into prevailing preschool cultures, as has also been previously described by Sundberg et al., 2018.

Aim of the Study

The overarching aim of this study is to investigate how digital and analog approaches influence multidimensional preschool science education. Specifically, we seek to analyze how preschool teachers at the forefront of digitalization integrate digital tools into their science teaching. In response to the research objective, we posed the following questions to drive the analysis:

- What digital tools do teachers integrate in their existing science activities to enable children's meaning-making?
- What science content do these science activities cover?
- What teaching dimensions are brought forward in the activities?

Methods

Preschool Context, Participants, and Data Collection

The data for this study consists of documentation of science activities submitted by ten Swedish preschool teachers (Table 1) and transcripts from recorded stimulated recall interviews with four of these teachers. All participating teachers had previously been participants in an interview study performed by the authors, where teachers' use and views on digital tools in preschool science teaching were the main focus (submitted manuscript). Ten of the thirteen teachers we approached agreed to participate further, and submit documentation of their digitalized science teaching. The selection of preschool teacher respondents with frontline knowledge and experience with digital tool integration was deliberate to provide new and rich information to respond to the aim of the study (e.g., Polkinghorne, 2005).

All ten participants worked actively with digital tools and science teaching, which was a criterion for participant selection. To locate preschool teachers who were skilled in using digital tools, we used various methods. For example, we asked for recommendations from scholarly and educational contacts who knew of teachers with experience in using digital technology. We also searched the Internet for Swedish preschool websites where teachers demonstrated how they integrated digital tools into their teaching. Additionally, we located one participant through self-made videos posted on YouTube. Seven participants were also responsible for the digitalization work of their own preschools, and three were advisers in digitalization at other preschools. These teachers, three males and seven females, represented nine different municipalities and ten preschools in different parts of Sweden. Work experience among the teachers ranged from 6 to 30 years, and their departments cared for, on average, 20 children. All preschools had access to digital tablets and projectors.

The documentation we requested was a written description of one science activity describing where digital tools contributed to the children's science meaning-making. Teachers were asked to attach multimodal materials (e.g., texts, photographs, movies). The participants had three weeks to prepare and submit their material. In some cases, without the researchers specifically requesting it, teachers complemented their original documentation with further material after one or two weeks. We decided to include these to follow the respective teacher's judgments of what was important to include. This resulted in an

Table 1 A framework describing seven teaching dimensions of preschool science, definitions, and discovered examples of related activities from our study (Expanded from Sundberg et al., 2019).

Teaching dimensions	Definition	Examples
1. Fantasy and play	Activities where children's imagination and reality are allowed to intertwine under playful forms.	Transforming a pine tree into a security guard by attaching artificial eyes to it. The security guard fires lasers at people who litter in the natural surroundings.
2. Travel in time and space	Using digital tools to speed up or slow down physical processes impossible to capture with the naked eye. Using tools to study distant objects or very small objects. Creating "time capsules" through assembling pictures and films from completed science activities to revisit.	Enlarging a bush cricket using a web egg connected to a digital tablet and thereby learning that bush crickets have ears on their front legs.
3. Empathy, ethics, and moral issues	Activities that support society's common values of caring for other organisms, humans, animals, and plants.	Watching and filming a frog in a brook without disturbing it with the help of a small waterproof action camera.
4. Storytelling	Communicating or constructing stories in various forms.	Drawing butterfly pupae and telling a story about how a larva becomes a butterfly.
5. Embodiment and sensory experiences	Involving whole-body experiences through several individual senses such as taste, smell and touch.	Growing sunflowers in the preschool yard. Measuring the height with the children's own bodies.
6. Aesthetic modes of expression	Creating opportunities for the children to express themselves and create representations of scientific phenomena and objects with the help of different digital and analog visual modes.	Reproducing insects and spiders in different materials and placing them in a "nature room" at the preschool.
7. Emergent systematic inquiry	Providing opportunities for the children to participate in investigations through discussions, formulating hypotheses, challenging questions and (systematic) collection of evidence.	Looking for sowbugs in the forest to investigate how and where they live.

empirical data corpus encompassing, on average, half an A4 written output per teacher, with 91 additional photographs, four films (25, 35, 51, and 22 seconds, respectively), and one self-authored published article as described in Table 2.

To gain a deeper understanding of how the use of digital tools, science content, and teaching dimensions was manifested in the material, four of the teachers (two males, and two females) were later invited to also participate in stimulated recall interviews. The four interviewees (numbered 1-4 in Table 2) were selected based on qualitative features of the material they had sent in so that they together would represent both recurring traits and the range of digital tools and science content described by all ten teachers (see further details below). Stimulated recall can be used to investigate the connection between teachers' pedagogical beliefs and actions in a way that is impossible with ordinary interviews (Meade & McMeniman, 1992). In adopting at least two methods of gathering data, we pursued methodological triangulation to obtain credible data related to the research aim. In studies of preschools, video recordings of teaching sequences have typically been used as recall material (e.g., Fridberg et al., 2018: Stavholm et al., 2021; Sundberg et al., 2018). However, this study used the teachers' documentation as recall material.

Due to COVID-19 restrictions during the study period, the interviews were conducted via Zoom. Interviews lasted between 21 and 36 minutes and were guided by an interview guide. The guide contained questions about the features of the documented science activities teachers had provided. We asked about their reasoning behind their choices of digital and analog tools and science content and how this setup would provide the children with opportunities for quality meaning-making about the intended science learning object. Questions were also posed about what educational dimensions they judged to be central to their teaching. Before the interviews, the teachers were provided with a table that exemplified the teaching dimensions previously identified for preschool science: Fantasy and Play, Empathy, Ethics, and moral issues, Storytelling, Embodiment and sensory experiences, Aesthetic modes of expression, and Emergent systematic inquiry (Areljung & Sundberg, 2018).

Data Analysis

The empirical material submitted by the ten teachers was analyzed in two steps: First, a thematic content analysis was guided by the first two analytical questions stated in the aim of the study section. This first analytical step provided information about the digital and analog tools that the teachers used to shape their science teaching and what content they focused on. It also provided information to select the four teachers that were asked to participate in recall interviews. When interpreting science content, the term "emergent science" was central. This term has previously been used to emphasize the shift from viewing preschool science activities as mere concept learning and a way of reaching predetermined answers to scientific questions towards promoting children's scientific skills, attitudes, understandings, and language through shared investigations with their peers and teachers (Johnston, 2008; Larsson, 2013). Emergent science thereby relates to the general idea of "emergent learning," that is, the idea that children discern qualities that are essential to a specific discipline (Pramling Samuelsson, 2008). When children engage in science activities, their meaning-making may not only be oriented toward the science content but also towards aspects of systematic inquiry, such as making predictions and methodical comparisons. Therefore, in our analysis, we included activities that we proposed to be "emergent

Table 2 Documentation submitted by the teachers (designated numbers 1–10) showing types of material (written text, pictures, and video recordings) and characteristics of content. Teachers numbered 1-4 participated in interviews

	Types and extent of submitted material			Digital tools used	Science content knowledge and included inquiry processes
	Text	Pictures	Video		
1	1	3	-	Digital tablets, Digital projector. Applications: GarageBand, Keynote and iMovie	**Biology**: Habitats and anatomy of sowbugs **Observations, discussions between children and teacher**
2	1	4	-	Digital tablets, Digital projector. Applications: Colored Pencil app	**Biology**: Animal anatomy (cats) **Discussions between children**
3	1	9	-	Digital tablets, Digital proejctor. Applications: ReverX, Polyglutt, iMotion, and iMovie	**Biology**: Eggs as part of animals' life cycles **Discussions between children and teacher**
4	2	2	-	Digital projector, Digital tablets. Application: iMovie	**Physics and Chemistry**: The properties of air and water **Comparative observations** **Discussions between children and teacher**
5	3	20	4	Digital tablets. Action camera. Application: iMovie, Projector	**Biology**: Frog habitat and anatomy **Observations, discussions between children and teacher**
6	1	10	-	Digital tablets, Applications: Procreate Digital projector.	**Biology**: A snail and its shell pattern (anatomy) **Observations, discussions between children and teacher**
7	2	5	-	Digital tablets. Wifi microscope. Applications: iMovie, Projector	**Biology**: Butterflies and their life cycles **Observations, discussions between children and teacher**
8	1	16	-	Digital tablets, Wifi microscope, Digital projector	**Biology**: Characteristics of insect and spider anatomy **Observations, discussions between children and teacher**
9	1	17	-	Digital tablets. Applications: Polyglutt	**Biology**: Comparing seed germination and human pregnancy. Fruit kernels, umbilical cords, and fetuses **Discussions between children and teacher**
10	1	4	-	Digital projector, Digital tablets. Applications: YouTube, Time Lapse	**Biology:** Life cycles of butterflies **Observations, discussions between children and teacher**

systematic inquiry" to capture early attempts of using science-specific ways of exploring natural objects and processes.

In the second step, we re-analyzed the same material through the analytical lens of an adapted framework for multidimensional science teaching (Table 1) based on Sundberg et al. (2019). Here, we were guided by the third analytical question. After the first round of analysis, the framework was adjusted by adding one more dimension to the original: *Travel in time and space*. As described in Table 1, the final framework used in this study thus included seven teaching dimensions: Fantasy and play, Travel in time and space, Empathy, Ethics, and moral issues, Storytelling, Embodiment/sensory experiences, Aesthetic modes of expression, and Emergent systematic inquiry.

To gain a deeper understanding of how the use of digital tools, science content, and teaching dimensions was manifested in the material, we reapplied all three analytical questions on the transcripts from the four recall interviews. The transcripts from the four recall interviews were analyzed as follows. We marked sentence units, i.e., the statements in which the teachers' answers were directed towards the analytical questions to create four in-depth "stories" that described the teachers' use of digital tools and reasoning about this within a context. From these four, we chose the "stories" of teachers 1 and 2 to complement the results derived from the first analysis of the material from all ten teachers in the results section. We thus give examples of two ways of shaping digitalized multimodal preschool science defined by their most salient traits. These two were chosen as they were judged to exemplify the main characteristics of how the teachers conceptualized and integrated digital preschool science and their reasoning behind their choices of digital and analog tools, materials, science content, and teaching dimensions.

We pursued trustworthiness of our analytical procedure through the following two approaches. Firstly, asking the four participants to revisit their submitted materials during the recall interviews allowed us to apply a type of member-checking procedure for validating our analyses, in a similar fashion to that reported by Schachter and Piasta (2022). Secondly, we reviewed and discussed our preliminary results at several research seminars with external researchers and between the authors to increase reliability, which allowed for an iterative process of revising and refining our analyses and findings.

Ethical Considerations

The general requirements for research ethics of the Swedish Research Council (2017) were strictly followed in this study. Accordingly, participating teachers were informed through email and orally about their rights to withdraw their participation without explanation, as their cooperation was voluntary. The information included the study's aim and that teachers' identities would be protected and anonymized and that data would only be used for research purposes. As an additional confidentiality measure, numerals were used instead of names to denote the respective respondents. None of the children's identities were revealed in the material sent by teachers.

Results

The results are presented in two sections. We first provide a general description of how multimodal digitalized preschool science may be shaped based on the documentation provided by all ten teachers. These findings are then accompanied by two "case stories" based on data and excerpts from the recall interviews to provide in-depth examples of digitalized preschool science.

Multidimensional Digitalized Preschool Science: An Overall Picture

The Digital Tablet: A Hub that Intertwines Analog and Digital Experiences

At first sight, a rather uniform picture of a digitalized preschool science relying on digital tablets emerged. All teachers described science activities where digital tablets were used (Table 2). On a closer look, however, it appeared that the tablet seemed to function as a "hub" that connects different digitalized and analog ways of teaching science. In some cases, the teachers used tablets without combining them with other tools (such as projectors), for example, filming, taking pictures, searching for facts, and using different apps, e.g., drawing and painting. Nevertheless, in many cases, the tablet was connected to other digital tools, such as action cameras, microscopes, and projectors which enabled more children to participate and re-experience activities through films, photographs, and enlargements. These digital tools, in turn, were used to enhance analog explorations or experiences, for example, painting with brushes and liquid paint or looking, feeling, and smelling real insects and plants.

When it comes to science content, a general characteristic that emanated from the material is that all teachers (but one) covered science content associated with the discipline of biology (Table 2). Most of them included some kind of emergent systematic inquiry, such as observing, examining, and conducting experiments (Table 3). Among the activities that focused on biology, all apart from two documentations (from teachers 4 and 9) described activities that focused on zoology: animal habitats, life cycles, and anatomy of mammals, insects, spiders, and snails. One of the two activities that focused on plants can, in a sense,

Table 3 Teaching dimensions reflected in teachers' documentations. Teachers T1-T4 were interviewed. Numbers represent the following teaching dimensions: 1. Fantasy and play, 2. Travel in time and space, 3. Ethics, empathy, and moral issues, 4. Storytelling, 5. Embodiment and sensory experiences, 6. Aesthetic modes of expression, 7. Emergent systematic inquiry. For descriptions of the teaching dimensions, see Table 1

Teacher	Science content	Teaching dimensions							Total
		1	2	3	4	5	6	7	
T1	Habitats and anatomy of sowbugs	X	X	X	X	X	X	X	7
T2	Animal anatomy (cats)			X	X		X	X	4
T3	Mammals and oviparous species	X	X	X	X	X	X	X	7
T4	The properties of air and water	X	X		X	X		X	5
T5	Nature experiences and frog habitat and anatomy	X	X	X	X	X	X	X	7
T6	Snails and their shell patterns (anatomy)		X				X	X	3
T7	Butterflies and their life cycles	X	X		X		X	X	5
T8	Characteristics of insects and spiders (anatomy)	X	X		X	X	X	X	6
T9	Fruit kernels, umbilical cords, and fetuses	X	X		X	X		X	5
T10	Butterflies and their life cycles	X	X		X		X		4
Total		8	9	4	9	6	8	9	53

also be judged as zoology orientated, as fruit kernels were studied and used to discuss and compare the development of seeds and human pregnancy. In the activity that dealt with physics and chemistry content, the children and their teachers explored the properties of air and water.

Supporting Multidimensional Teaching with Digital Tools

The results presented in Table 3 are based on our analyses of the documentation that the ten teachers supplied. As shown in the table, all teachers described activities where multiple teaching dimensions (Table 2) were included. In the next section, we describe the activities of teachers 1 and 2 in greater detail to help the reader follow how we identified the specified dimensions in the teachers' documentation.

The dimensions of Fantasy and play, Travel in time and Space, Storytelling, Aesthetic modes of expression, and Emergent systematic inquiry were all commonly included in the activities. Three of the teachers described activities that integrated all seven dimensions. The least commonly revealed dimension was Ethics, empathy, and moral issues. Only four of the teachers' documentation included these dimensions.

As described in the methods, teachers 1 to 4 (Table 2) also participated in stimulated recall interviews. In the next section, we present results from two of these four stimulated recall interviews to provide examples of a contextualized picture of the teachers' work with digital tools in preschool science, and their reasoning behind their pedagogical choices. These two cases were purposefully chosen as they were judged to exemplify the main characteristics of how the teachers conceptualized and integrated digital tools, and their reasoning behind their choices of digital and analog tools, materials, science content, and teaching dimensions.

Two Case Stories with Preschool Teachers at the Forefront of Digitalization

The first story exemplifies a case where the teacher used digital and analog tools to forefront all seven teaching dimensions. The second story exemplifies how digital tools can reinforce social learning, inclusion, and agency during science activities, a very important representation of the Swedish educare approach.

Teacher 1: Multidimensional Science Teaching by Combining Digital and Analog Tools

Teacher 1 pushes the boundaries of multidimensional science by combining digital and analog tools when exploring the local environment and its organisms. The material submitted by teacher 1 exemplifies how multiple digital and analog tools can be combined to provide children with multimodal experiences of the local environment and its organisms. The activity was part of a larger science project focusing on the local environment and its organisms and was initially planned to focus on insects. However, the children were more interested in sowbugs (which are not insects) so the teacher adjusted the science content accordingly. The teacher explains:

> The children's interests are always the driving force; // also [we always] include spontaneous situations not planned for from the beginning. (teacher 1)

At the start of the activity, the teacher and the children explored where and how sowbugs live during excursions, where they used digital tablets to document their findings about sowbugs and their habitats. Throughout the excursion, the children could share their questions and thoughts about the sowbug habitats, where aspects such as temperature and moisture were discussed and experienced hands-on. The teacher encouraged and emphasized discussions about how to care for living organisms such as animals and each other.

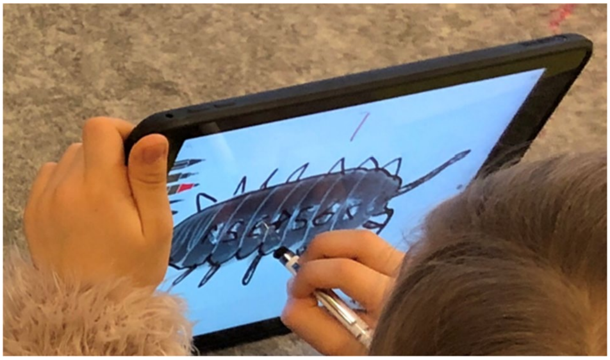
In this first part of the activity, we judge that the teacher has included *Emergent systematic inquiry* through the investigations of the habitats of the sowbugs, and *Embodiment and sensory experiences* through real-life experiences of the temperature and moisture of their habitats. In addition, combining these above experiences with discussions of society's shared values of animal rights, the dimension of *Ethics*, *empathy*, *and moral issues* was included (see Table 3).

When returning to the preschool, the digital tablets and a projector were used to include the dimensions of *Travel in time and space*, *Aesthetic modes of expression*, *Emergent systematic inquiry*, and *Storytelling*. The children could re-experience the event ("travel back in time") by watching filmed and photographed sequences of the excursion and "travel in space" through enlarged photos taken of the sowbugs they had encountered in the forest. The teacher describes how this way of working was also designed to invite all children to participate in a shared experience:

> The digital tools allow us to take photos and enlarge them; we can count the shields on the sowbug and see how many legs it has…by projecting up, everyone can take part in it. (teacher 1)

The children also made their visualizations of sowbugs by reproducing the pictures in different ways (*Aesthetic modes of expression*), first, by drawing them both using analog tools, such as crayons on paper, and then digital tools (drawing apps on tablets). One of the ways the tablets were used is displayed in Fig. 1, where a child is adding features to a digital picture of a sowbug retrieved from the internet. As part of observing closely (*Emergent systematic inquiry*), the child has counted the number of back plates and legs, typical features of crustaceans, and when doing so, struggled to generate the shapes of the numbers on the sowbug's back plates (Fig. 1). Secondly, they created sowbugs in clay and placed them on a bookshelf decorated to mimic their natural environment. In the next step, the teacher and the children created a music video with the digital tablet, namely a song with an emotional text about a frog and a sowbug that fall in love (*Storytelling, Fantasy and play*). This was combined with descriptions of sowbugs and their characteristics that were added to the background that was based on the children's drawings (both analog and digital).

Fig. 1 A child uses a digital tablet to observe, paint and explore a sowbug



During the interview, the teacher described how this way of working with digital tools also made way for children's motivation, creative thinking, and cooperation during science activities:

> Digital tools can work as an accelerator ... you see in the children when they have created a book or film that they want to create more ... when the children obtain this digital competence, a lot of exciting ideas are born. (teacher 1)

And:

> There was much focus on creative thinking, collaboration, and communication and those aspects of teaching. (teacher 1)

Apps used in the activity (apart from those pre-installed) were Keynote, iMovie, and GarageBand. Taken together, we see that all seven dimensions were included in this described science activity (Table 3). This is in line with the teacher's own judgement.

Teacher 2: Multidimensional Science Teaching for Promoting the Educare Culture

Teacher 2 uses digital tools to teach anatomy and reinforce social learning, Inclusion, and Agency, and describes two activities through photographs and text (Table 2). Both these activities were purposely designed to combine the affordances of analog and digital tools to make way for learning about animal anatomy while also encouraging children's agency and communication.

The first activity is pictured in Fig. 2, where one child is drawing a cat (*Aesthetic modes of expression*) on a digital tablet using the Colored Pencil app. The tablet is connected to a projector so that the drawing process can be observed by a group of children who can then mimic each step of the drawing process while drawing on their own paper or tablet. The task for the child who draws on the tablet connected to the projector is to also verbally instruct the others. During the interview, the teacher describes that by providing the children with different modes when drawing pictures, it is possible to include all children in the activity. The teacher explains:

> Some children want to avoid holding brushes and getting messy. These children can now participate and draw on a digital tablet ... a digital [tool] is a good alternative that allows everyone to participate. The digital can also become a step into the analog… For me, digital and analog go hand in hand; digital cannot stand

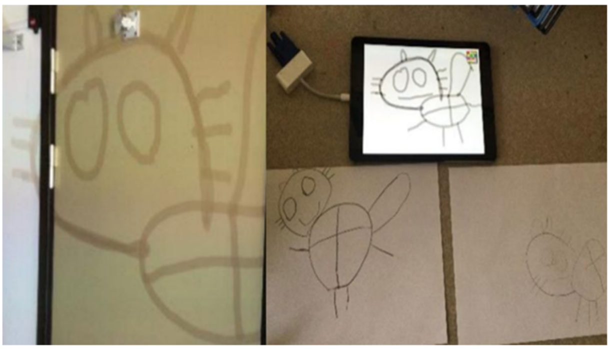


Fig. 2 A collage of children's digital and analog visual outputs of cat anatomy

alone //. By using the projector, participation among more children is created. I always have a conscious thought behind the activities. (teacher 2)

The task for the other children is to do their best to draw a similar picture based on what they see and hear. By using digital tools in this way, the teacher purposely makes it possible for several children to participate simultaneously, and to communicate with each other about what they are doing, something that the teacher values as important. During the interview, the teacher specifically commented that in addition to learning about a cat's body structure, this was an exercise in communication between the children. Therefore, the teacher also encouraged the children to practice how to ask relevant questions about the features of the cat's body to help them draw their cats' bodily structures as accurately as possible. For example, she encouraged a discussion about the structure and the function of the cat's whiskers. This aligns well with the definition of *Emergent systematic inquiry* where the children should be provided opportunities to participate in investigations through discussions, formulating hypotheses, challenging questions, and (systematic) collection of evidence. In the activity, the children are investigating and inquiring together about cat anatomy (the structure of a body) through joint drawings and discussions.

At the same time, the task-leading child gained an experience of agency from having the opportunity to lead an activity, having something important to convey, and being listened to by the other children. When doing so, the instructing child also had to find ways to convey and articulate his or her views on drawing a cat. Teacher 2 sums up that this activity was a way to afford the children opportunities to grow together, something this teacher values as an asset in scientific contexts. When asked which dimensions were included, the teacher identified the same four dimensions as we identified in our analysis (Table 3).

Discussion and Implications

This study focuses on preschool science education and how the integration of digital tools influences preschool teachers' science teaching. Our overall interpretation gained from the results confirms that preschool science is firmly historically and culturally situated. All teachers provided documentation that described innovative digitalized science activities that still aligned with the educare culture that characterizes Swedish preschools. More precisely, all teachers intertwined dimensions such as fantasy, play, empathy, aesthetic modes of expression, and storytelling, as well as embodied and sensory experiences with systematic inquiry and learning of science facts. Our results thus exemplify that digital tools can be used to push the boundaries of multidimensional science teaching while maintaining the core values of the curriculum. Nevertheless, the results also indicate that this firm alignment with a prevailing preschool culture also sets limits to renewing preschool science. Although the participating teachers in this study are innovative in their approaches to teaching science, biology, the discipline that traditionally dominates preschool science dominates among the examples of communicated digitalized preschool science activities. In the following section, we discuss these findings and provide insights into how preschool teachers can use digital tools to complement, strengthen, and diversify the use of analog tools and identify both opportunities and challenges for digitalized preschool science.

Pushing the Boundaries of Multidimensional Science Teaching While Maintaining the Core Values of the Curriculum

Our results show that preschool science can remain multidimensional and child-centered even when digital tools are introduced. The material provided by the preschool teachers that participated in our study describes activities embedding all the dimensions previously described for multidimensional preschool science (Areljung & Sundberg, 2018; Sundberg et al., 2019). In fact, we identified one more teaching dimension that could be directly connected to the use of digital tools, namely *Travel in time and space* (Table 1). This finding is in line with other studies that have suggested that digital tools, with their multiple modes, can offer essential means for meaning-making and inquiry in preschool science (Kewalramani & Veresov, 2022). We interpret that our results reflect a strong preschool culture where core values are as important as the science learning object for the participating preschool teachers. Our results however deviate from previous results asserting that traditional curriculum goals tend to take over science teaching in preschool settings (Sundberg et al., 2018; Westman & Bergmark, 2014) as the teachers successfully balance and intertwine the curriculum's goals regarding core values and the subject of science with digitalization. Our results also contribute novel knowledge that can inform possible risks of introducing digital tools into preschools. For example, Nilsen (2018) has highlighted the risks of foregrounding digital tools in favor of analog tools. Our results reveal that the interviewed teachers explicitly express that digital tools can be used to strengthen and diversify analog resources. They regard *both* digital and analog tools as essential and *complementary* rather than digital being deemed superior to analog or vice-versa. We interpret our results as connected to the fact that the preschool teachers in our study were knowledgeable, interested, and confident in their roles in connection to both science teaching and digitalization. Competence and confidence have previously been identified as key for quality teaching in preschools (Barenthien et al., 2020; Inan & Lowther, 2010; Nayfeld et al., 2011), as well as for handling digital tools when teaching science (Walan & Enochsson, 2022). Our results also indicate that the teachers in our study have had an array of digital resources at their disposal judging by the various apps and digital tools that they have used (see Table 2), something that is not always the case in Swedish preschools (Otterborn et al., 2019). Hence, our results serve to imply what might be possible when teachers are provided with opportunities to develop their competence through appropriate digital resources, rather than provide a general picture of digitalized preschool science.

Digitalized Science Teaching Supports Traditional Preschool Science Content

Traditionally, preschool science has focused on the scholarly discipline of biology. This preference for biology has persisted despite several initiatives to introduce chemistry and physics into preschool science (Swedish Schools Inspectorate, 2017; Westman & Bergmark, 2014). It is therefore interesting to note that although the participating teachers in this study are innovative in their approaches to teaching science, biology, with a focus on animals, remains the preferred discipline. Only one of the ten teachers described examples connected to physics and chemistry. This result is a reminder that digitalization alone is not a vehicle nor silver bullet for the renewal of all aspects of science teaching. Our results suggest that even experienced and confident teachers need specific support to find their way into new disciplines within the natural sciences. Pointing in this direction is that the only teacher in our study that worked with physics and chemistry had access to an analog "toolbox" for explorations about the properties of air and water provided by the non-governmental association science and technology for all (NTA). These boxes, with ready-made materials, including a teacher's guide, have previously been described as appreciated support by early years teachers (Walan & Mc Ewen, 2017).

Conclusions and Implications

The novelty and contribution of this study is that it exemplifies how preschool teachers can use digital tools to push the boundaries of multidimensional science in a way that still acknowledges the specific core values of preschool practice. The results can be used by preschool teachers who seek inspiration and support for integrating digital tools in connection with science teaching, something that teachers are requesting (Otterborn et la., 2019; Walan & Enochsson, 2022). Specifically, we note that digital tablets seem to be a versatile tool when pushing the boundaries of science teaching. From a science teaching point of view, they provide teachers with a vast array of applications that together with other artefacts and modes (e.g., Kress, 2003) enable novel ways of exploring the surrounding world as discussed by Fleer (2009a, 2009b) and Johnston (2014). In Sweden, this type of digital tool is already very common in preschools. In the case of the experienced teachers in this study, they have used the tablets as a hub from which to push the boundaries of digitalization in preschool science education further. At the same time, digital tablets might also provide a first scaffold for preschool teachers that still feel uncomfortable and uncertain with integrating digital tools. Nevertheless, leveraging the pedagogical potential of digital tablets in practice still requires thoughtful competence development, as well as knowledge about appropriate applications. Many preschool teachers active in digitalization are eager to develop the use of digital tools with many seeking and demanding such competence development (Otterborn et al., 2019; Walan & Enochsson, 2022). While there are clear potential benefits of integrating tables in preschool education, it is important to acknowledge that there are also certain associated risks that policy and educational role players need to consider (Kjällander, 2019; Nilsen, 2018; Sakr, 2019; Selwyn, 2016; Williamson, 2016).

When analyzing the science activities, we used an empirically and theoretically underpinned framework to articulate and describe if, or in what ways, digitalized science teaching impacts multidimensional preschool science. This framework might be useful in further research as well as by in-service teachers and teacher educators for analyzing preschool practice. Finally, we recognize that our results confirm that core values and traditional teaching contents of prevailing educational cultures are situated (Engeström, 1987; Lave & Wenger, 1991). Hence, the historical and cultural contexts provide structure and meaning to preschool science activities, as previously suggested (Sundberg et al., 2018). This seems to remain true even for digitalized preschool science, at least when teachers have been provided with support to develop competence and confidence as well as appropriate equipment. The emergence of digital tablets, with their user-friendly and intuitive design, could be seen as an incentive for the continued adoption of digital technologies in preschool settings. Future direct observations of teachers' and children's digitalized science education activities in practice could be a potential subsequent step for gaining further insight into this area.

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Data Availability The anonymous data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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