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Empowerment of Science Education for Young Children

Current Research and Implications for Learning

Edited by
Alice Delserieys Pedregosa and Maria Kampeza

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Maria Kampeza is Associate Professor at the University of Patras, Department of Educational Sciences and Early Childhood Education in Greece. Her research interests focus on young children's learning and development in early science education, participatory learning processes (such as play and drawing), differentiated instruction, school–family partnerships, and pre-service and in-service teacher education. Her research has been published in peer-reviewed international journals and edited volumes as well as presented at both international and national conferences. Since 2009, she has coordinated the teaching practicum of university students in Greek public kindergartens, contributing to the professional preparation of future early childhood educators. She has also participated in funded research and educational projects, including Voicing Children: Opportunities, Interaction, and Collective Decision Making in Education, Teaching Experimentation in Science and Technology, and The Fibonacci Project: Disseminating Inquiry-Based Science and Mathematics Education in Europe. In addition, she has served as a tutor in Professional Development Programs for Early Childhood Teachers, supporting ongoing professional learning and pedagogical innovation.

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Editorial

Current Research and Learning in the Field of Early Childhood Science Education

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Abstract

Although the education of young children in science is not a completely novel field of research, recent years have seen a renewed interest and a shift in research discourse toward addressing contemporary challenges and dilemmas. Within this, some features maintain continuity with past traditions, developing them to a place of contemporary relevance, as is the case for the focus on children's perceptions of various scientific concepts and phenomena as well as teachers' perspectives on these issues. At the same time, new research dimensions have emerged that focus less on the "what" of learning and more on the "how". In this direction, innovative educational practices are being designed and implemented, diverse forms of representation and expression are being exploited, and learning contexts are broadened. This article presents such research directions and perspectives on early childhood science education that advocate more participatory and inclusive approaches, more attuned to the multiple forms of expression that young children use to make sense of the world.

Keywords: early science learning; children's perception; teacher's perception; research trends

1. Introduction

Scientific thinking is not the prerogative of adulthood. It begins in early childhood when children engage with their world through exploration, questioning, and meaning-making. Although early childhood education has been a long-established field of research, a specific focus on science education during early childhood years emerged relatively recently, but displays constant development (Ravanis, 2017; Siry et al., 2023). Recent shifts in early childhood science education emphasize the consideration of young children as informed participants rather than passive learners. This Special Issue of *Education Sciences* showcases contemporary research at the intersection of early childhood education and science learning, reflecting a growing consensus on the value of scientific experiences in early years. Each contribution included in this issue reveals how young children develop scientific concepts, how teachers and contexts shape these learning trajectories, and how innovation, from augmented reality to nature-based education, can engage children in inquiry activities. In addition, the importance of creating rich and diverse learning environments that encourage children to explore, experiment, and understand the world in a scientific way is highlighted. Collectively, the articles included in this Special Issue underscore the importance of listening to young children, amplifying their voices, and situating science learning within real-world contexts. From this perspective, science is presented in an accessible and engaging way with the potential to become a powerful tool for developing children's critical thinking, creativity, and confidence. As Siry, Cabe-Trundle, and Sackes (Siry et al., 2023) point out, "early years science education can lead to important outcomes, which go beyond discreet skills and content knowledge" (p. 3).

A lot can be learnt from children when they are given the opportunity to participate in the processes that concern them and are valued as competent communicators. The acknowledgement and acceptance of this approach also opens up a new framework for research in early childhood education by positioning children as 'experts' on the issues affecting their lives and requiring the development of new ways of communicating and exploring children's perspectives in order to enable them to participate in data collection, processing, and analysis. In other words, children's participation refers to processes in which children activate their thinking (Clark & Flewitt, 2020). Grounded in sociocultural theory, we advocate a participatory view of learning where young children are not passive recipients but active meaning-makers and contributors. Many research perspectives remind us that children's learning stems from participation in culturally and socially mediated practices (Hedges & Cullen, 2012; Hedegaard & Fleer, 2008). From this stance, research that recognizes children's agency, symbolic capacities, and collaborative engagement enriches both theory and practice. Co-research with children gives them the opportunity to develop a wider range of skills and to try out different roles without this necessarily implying that the teacher or researcher abandons their own role as researcher; the nature of the role changes as new opportunities to co-construct meanings emerges.

Our view is further supported by the recent review of early childhood science education conducted by Siry, Cabe-Trundle, and Saçkes (Siry et al., 2023), who emphasize that the field has evolved significantly in the last two decades to recognize the value of inquiry, play, and holistic approaches to science education. They highlight how scientific thinking and modeling are achievable by young children and stress the importance of early experiences in fostering lifelong scientific literacy. Their findings echo the trends highlighted in this Special Issue and the specific consideration they afford to young children's engagement in science activities.

2. The Importance of the Empowerment of Science Education for Young Children

According to the sociocultural perspective, each class is a context with its own particular practices that allow its members to co-construct common meanings by participating in classroom interactions (Hedges & Cullen, 2012). Learning is related to the children's involvement in processes and different types of activities available to them, which concern both the way in which children participate and the knowledge they gain through them (Hedges & Cullen, 2012; Rogoff, 2008). Therefore, it is important that learning and teaching focus on children's potential for learning and the exploitation of their perspective.

Educational research can incorporate participatory processes using appropriate tools, as has been demonstrated in recent years by the application of the Mosaic Approach, as formulated by Clark and Moss (2001, 2005). Participatory research gives children the opportunity to take an active role in the construction of meaning and knowledge and to make their own perspective visible. This perspective can then be used as a guide to redefine the perspective of researchers and teachers, creating opportunities to consider children as 'co-researchers', meaning they are willing to leave space for children to take initiative and share the 'power' of each interpretation with them.

The extent to which children can participate depends not only on their own abilities but also on teachers' perceptions of these abilities, which ultimately influence the practices teachers adopt in the classroom. Children's perspectives and learning processes are recorded in different ways so that they can be shared, discussed, and reflected upon, therefore meaning that they often take responsibility for contributing to their own learning and to the group's projects. Traditional methods of observation and interviewing have been enhanced by participatory tools that children themselves can use (e.g., photographs, creating books, maps, etc.). This shift is particularly vital in the context of early science education, where children's ideas, emerging conceptual frameworks, and everyday experiences play a formative role in how they make sense of the natural world. Involving children as informants respects their agency and affirms their capacity to contribute meaningfully to educational research and practice. In science education in particular, where curiosity and interest are foundational, children's questions or reasoning act as entry points for meaningful learning and teaching and such contributions challenge researchers and educators to design more responsive, inquiry-based curricula. Participation in research can also have an empowering effect on children themselves. When they see their voices valued, their ideas taken seriously, and their questions explored collaboratively, they develop a stronger sense of self-efficacy and intellectual agency (Kampeza & Delserieys, 2020) which in turn leads them to develop a deeper engagement with science as a way of thinking, questioning, and understanding the world.

To summarize, the studies included in this Special Issue can help us realize that recognizing young children as informants is not a methodological luxury—it is a prerequisite for empowering science education that is inclusive, dialogic, and grounded in the lived realities and imaginative capacities of early learners.

3. Research Trends and Implications for Learning

Emerging evidence presented in this Special Issue underscores a shift in how we view early science education. Collectively, these works highlight innovative approaches that support children's early capacities for complex thinking, from digital tools and multimodal representations to child-centered inquiry and enhanced teacher preparation. In recognizing preschoolers' abilities to grasp scientific concepts, researchers are pointing toward enriched curriculum and pedagogical designs that leverage expression, play, technology, and guided inquiry. These trends carry significant implications for early childhood science teaching practice, suggesting the need for learning environments that nurture child agency, incorporate novel educational tools, and empower educators to facilitate deep science learning from the earliest years.

3.1. Children's Conceptions, Models, and Ideas in Science

The way in which children think and their ideas about the concepts and phenomena of the world around them have different starting points and are constantly changing. One important theme present throughout the current research in early science learning is the capacity of young children to engage with sophisticated scientific ideas when given appropriate support. Several studies demonstrate that preschool-aged children can form meaningful conceptual understandings that have sometimes been considered "too advanced" for their age (Eshach & Fried, 2005). Learning is a dynamic process that requires the child's genuine participation in order to create his/her own meanings (Rogoff, 2008). Although in relevant research concerning young children's beliefs and ideas, a number of terms are used that often indicate difficulties or misunderstanding, such as alternative conceptions, misconceptions, mental representations, etc. (Ravanis, 2022), there is a constant interest in exploring children's thought and the way they comprehend scientific concepts and phenomena. The current perspective does not focus so much on mapping the difficulties leading to the divergence of mental representations from knowledge gained in school, but rather aims to highlight the range of skills, knowledge, and abilities available to children which are shaped in their family and social life. Thus, researchers and teachers who adopt this dimension bring more participatory practices into classrooms, giving children the opportunity to make use of their funds of knowledge (Hedges & Cullen, 2012).

An example of this approach can be seen in the work of Christodoulakis and Adbo (2024), who conducted a longitudinal, play-based intervention exploring how preschoolers develop chemical concepts. Drawing on framework theory, they documented how 3- to 5-year-olds shift from intuitive to scientific conceptions of matter using embodied activities, metaphor, and visual representations (e.g., "tiny balls inside everything"). Children viewed zoomed-in videos and engaged with storytelling and material-based activities. The results suggested that children's ontological frameworks evolve with structured multimodal interventions as they found that 4–5-year-old children began to construct an interconnected network of scientific concepts about matter at the submicroscopic level. The children in their study could imagine invisible particles and understood that water retains the same tiny "balls" (molecules) in different states, indicating an emerging grasp of molecular ideas. With regard to teacher training, this reinforces the need for epistemological awareness and scaffolding strategies that align with children's intuitive models.

Similarly, Jelinek's (2024) intervention on conceptualizing the Earth's shape foregrounds the significance of children's mental models and their evolution over time. Jelinek's work contributes to the research concerning children's ideas and appropriately organized educational activities that can be effective in supporting children, using the example of how forming the concept of a spherical Earth can act as an essential starting point for understanding elementary astronomy. The use of the EARTH2 test allowed children to express their conceptual frameworks through visual selections, reflecting internal models of understanding. Through a multilevel educational intervention with 7–8-year-olds, the author shows that model building (with a ball-Earth) prior to using the globe as a codified artifact enhances the cognitive integration of the concept of globality. The intervention additionally enhanced children's curiosity and led to spontaneous questions about Space that extended far beyond the scope of the school curriculum.

Ioannou, Kaliampos, and Ravanis (Ioannou et al., 2024), on the other hand, deal not only with the transformation and evolution of children's mental representations but also with the formation of precursor models in children's thinking. Their research concluded by acknowledging that it is possible to some extent to transform young children's initial mental representations into representations compatible with school knowledge. More specifically, they address children's mental representations of clouds, as well as condensation and the precipitation of water vapor, implementing a qualitative study involving 19 preschool children. The survey included pre-tests and post-tests for recording children's mental representations, as well as a structured teaching process adapted both to children's cognitive needs and the conditions of a real classroom.

3.2. Teaching Strategies

Across these studies, there is a strong emphasis on teaching strategies that adopt child-centered inquiries in early science learning. Young children are not just capable of absorbing scientific facts, they are inclined to practically *do science* when provided with the right opportunities. More importantly, with the appropriate scaffolding, children can develop first understanding of science concepts and scientific reasoning skills.

In their study of young children's mental models of condensation, Ioannou, Kaliampos, and Ravanis (Ioannou et al., 2024) also introduce interesting teaching strategies for kindergarten settings in Greece. The teaching strategy they developed followed an inquiry-based, four-step engineering design process: problem definition, exploration, modeling, and testing. Their research results showed a transition from fragmented ideas ("clouds are sponges") to cohesive precursor models incorporating key features of scientific models (e.g., invisible vapor, cooling). In stressing the importance of sustained, structured inquiry within playful contexts, these findings also suggest that teachers may benefit from professional development that focuses on designing science activities with iterative modeling opportunities.

García-Rodeja, Barros, and Sesto (García-Rodeja et al., 2024) present a case study of undertaking inquiry activities about woodlice with 3- to 5-year-olds. Over seven sessions, children generated hypotheses, conducted observations, and participated in designing simple experiments. The study documents children's challenges with experimental control but highlights their ability to express curiosity, categorize traits, and adapt their thinking through dialog. Their study outlines the key elements that support inquiry-based teaching for early science education, and, in particular, stresses the importance of prioritizing support for planning inquiry sequences, guiding observations, and creating the conditions for young children to articulate their scientific reasoning.

In a complementary study, Papantonis Stajcic, Vidal Carulla, and Åkerblom (Papantonis Stajcic et al., 2024) analyze Swedish preschoolers' questions during a digital interactive chemistry session. Children asked spontaneous questions (e.g., "Can molecules dance?") that reflected imaginative reasoning and prior experiences. The findings reveal the value of children's questions as entry points into complex science content and advocate for training teachers to use children's questions as didactic tools.

The main idea confirmed in these studies is that inquiry processes can take root in early childhood (Siry et al., 2023). Young learners enjoy activities where they can explore phenomena, ask questions, and attempt explanations, even if they require guidance to fully make sense of the outcomes. These findings align with broader research suggesting that play and inquiry in the early years build the foundation for scientific thinking by cultivating curiosity, observation skills, and reasoning (Siry et al., 2023). Early childhood science teaching strategies should foster opportunities for open-ended exploration and guided inquiry, where children's ideas drive the investigations and teachers act as facilitators who support children in the inquiry process. Engaging in such inquiries and play activities is important in early educational settings, not only for the development of scientific skills, but also of scientific knowledge and scientific reasoning, which later support problem solving and critical thinking (Vartiainen & Kumpulainen, 2020).

3.3. Engagement in Different Forms of Representations and Expression

In the logic of strengthening participatory methods, given that the use of children's perspectives brings us closer to their lives and understandings, a combination of traditional methods of observation and interviews with children with more participatory tools is attempted (Clark & Flewitt, 2020). A number of studies presented in this issue incorporated drawing, language, digital media and videos, or immersive experiences to make science concepts accessible and contribute to the important task of nurturing young children's thinking from an early age (Salmon, 2016). Often, offering children the opportunity to express their views is insufficient, and it can be more interesting to provide them with different ways and tools to convey their ideas. Teachers' training and professional development programs could incorporate such proposals that involve finding appropriate ways to access children's multiple views of specific science topics. If educators allow children to act as agents and actively listen to their diverse voices, they may gain important contributions to facilitate learning that would otherwise be missed (Rogoff, 2008; Kampeza & Delserieys, 2020).

In their study, Kampeza and Delserieys Pedregosa (2024) analyze how young children represent their understanding of physical changes in matter—specifically melting and freezing—through drawing, highlighting the importance of using drawing to reveal children's rich repertoires of signs and symbols in science. Using a sociocultural lens, they examine 4- to 6-year-olds' symbolic and iconic representations and identify how different drawing tasks triggered different representational modes, scaffolding scientific thinking. Their study, combining classroom-based storytelling and observation with task-specific drawing prompts, demonstrates that children creatively blend everyday and scientific understandings. When children combine their own symbols with symbols they are familiar with from their everyday environment, they use codes, which they gradually adapt and improve. In relation to teacher training, this finding implies the importance of integrating symbolic tools into science pedagogy and encouraging diverse representational modes to help children articulate and develop early scientific models.

Fridberg and Redfors (2024) explore how two Swedish preschool teachers used augmented reality (AR) to engage children with the Sustainable Development Goals. Through place-based thematic teaching supported by AR applications, children explored issues such as plastic pollution. They guided students to link, confirm, and expand meanings across representations, referring to transduction as the process where children experience meaning from a specific content based on the experience of several different representations of that content that teachers help them to link together. The study shows how AR facilitated transduction between real environments and symbolic representations, fostering agency and critical reflection. Teachers initially approached AR cautiously but came to view it as a tool for enabling children's social participation. "The children transduced their knowledge and meaning of the SDGs between representations in the physical world such as local places, paper drawings and recycled materials and the digital world with the colorful SDG symbols in AR applications" (p. 12). These findings call for teacher preparation programs to support confidence in digital pedagogies while situating technology within inquiry and critical engagement.

A study by Papantonis Stajcic, Vidal Carulla, and Åkerblom (Papantonis Stajcic et al., 2024) provides valuable evidence for the use of diverse forms of representation and expression in early science education. Conducted during the restrictive context of the COVID-19 pandemic, the study implemented an interactive digital learning approach in which young children were introduced to abstract concepts such as molecules and matter through prerecorded videos. These videos featured dramatizations, using dance, theatrical play, and gestures, performed by drama educators. The sessions were followed by a question-and-answer forum with a chat function, allowing children to pose questions to adults with chemists' expertise. Analysis of the children's questions revealed how this interactive digital environment enabled them to connect scientific content with everyday experiences, play, and imagination. The authors suggest that digital lessons can effectively introduce and illustrate abstract concepts like molecules and matter through multimodal approaches. As mentioned earlier, this multimodal approach is further deepened by the questioning approach supported by teachers.

Similarly, Christodoulakis and Adbo's (2024) use of "zooming-in" animated videos of microbes and molecules provided preschoolers with a concrete representation of invisible phenomena. Through these visualizations, children were able to describe microscopic germs on leaves and recognize that tiny unseen particles (like salt grains too small to see) exist and matter in explaining real-world outcomes. Such multimodal representations (visual, kinesthetic, etc.) serve as powerful bridges from the known (the observable world) to the unknown, enabling young learners to conceptualize scientific realities that lie beyond direct perception. By zooming in and visualizing the microscopic world, Christodoulakis and Adbo show that preschoolers can engage with complex ideas like microorganisms and molecular structures when these are presented in an age-appropriate manner. Their work adds a valuable dimension to the Special Issue, demonstrating the impact of creative, multimodal pedagogy on expanding children's scientific understanding. The study suggests that introducing "invisible" scientific phenomena through imaginative visual and hands-on experiences not only raises children's interest but also lays the groundwork for deeper scientific literacy from a very young age.

3.4. Teachers' Perspectives

The reflection on early childhood science education, presented through these studies, places heavy demands on the role of the teacher and the quality of teacher preparation in early science education. If young children are to engage in activities that develop their scientific thinking and conceptualization, educators must be equipped to guide and scaffold their experiences. However, a noted challenge is that many early childhood educators feel underprepared to teach science effectively, especially in ways that also support diverse learners (Areljung, 2019). This concern is directly addressed by studies in the Special Issue focusing on professional development and teacher attitudes.

Chen, Sermeno, Hodge, Murphy, Agenbroad, Schweitzer, Tsao, and Roe (Chen et al., 2024) present a mixed-methods study of a year-long professional development program in Idaho focused on metacognition-driven science teaching, involving 20 teachers and 110 children aged 4–6. The quantitative results showed increases in teacher science self-efficacy and metacognitive awareness. In the teacher's classrooms, the researchers measured corresponding increases in children's self-regulated learning skills. The qualitative findings from this study further revealed that after the intervention, teachers were providing richer science activities that not only taught science content but also supported children's learning in literacy, math, and social–emotional domains through integrated, reflective practice. The study confirms that professional development programs aligned with child development and science teaching can transform the beliefs and practices of teachers. It is also made clear that young children benefit broadly by becoming more self-directed learners and connecting science with other areas of development.

In a similar vein, Young, Hoisington, Kook, and Ramer (Young et al., 2024) report on a multifaceted professional learning program aimed at empowering preschool educators to engage emergent multilingual learners (EMLs) in science, in partnership with families and community science centers. Their quasi-experimental study showed that educators who received in-depth training and support grew significantly more confident in science teaching for diverse learners, compared to a control group. These teachers, in turn, provided higher-quality classroom science experiences. Their research also highlights that, with appropriate training and community engagement, teachers can ensure that all children, including dual-language learners, have access to high-quality science learning in their formative years.

However, improving teacher readiness for early science is not only a matter of offering professional development. It also involves addressing the underlying beliefs of teacher and their pre-service education. Pahl and Tschiesner (2024) examine the attitudes of Swiss trainee teachers toward the multidisciplinary subject Nature–Human–Society. Using qualitative and quantitative data from 220 student-teachers, they found that many trainees reported discomfort or low interest in teaching science topics, with lower preference and self-efficacy for teaching physics and technology compared to biology and social science. When asked to justify their preferences, the most common reasons for putting aside certain science topics were a lack of confidence (low perceived control over the content) or a lack of personal connection to the material. In contrast, the topics they enjoyed teaching were those they felt more knowledgeable about or emotionally drawn to. This dichotomy is important because it suggests that without intervention, teachers might unintentionally prioritize content they are comfortable with and omit key science concepts in early education.

This research reinforces the idea that teacher education programs must proactively build strong science content knowledge and positive dispositions towards it in future educators. The authors advocate for building a deeper understanding of science topics but also emphasize the importance of fostering a positive experience of science with inquiry-based science learning experiences for teachers themselves, in order to help new teachers overcome anxiety and develop a sense of ownership towards teaching science. The goal is to cultivate educators who are both confident and competent in facilitating early science, thereby ensuring that innovations like those put forward in this Special Issue can take root in real classrooms.

3.5. Questions About Contexts and Learning Environments in Early Science Education

A final trend emerges from the research in this Special Issue, which is the consideration that a community and environmental orientation in the curriculum can broaden learning contexts. Field trips, outdoor learning sessions, gardening projects, and community projects or partnerships with science museums and parks can situate children's learning in authentic contexts. Such approaches not only reinforce concepts through multiple contexts but also affirm cultural and linguistic diversity, in particular by engaging parents and community members as partners in science learning (Siry et al., 2023).

The learning environment, both physical and social, yields specific experiences and interactions. In this Special Issue, the scoping review of Trina, Monsur, Cosco, Shine, Loon, and Mastergeorge (Trina et al., 2024) examined how nature-based outdoor environments contribute to preschoolers' STEAM learning, with STEAM approaches integrating science technology, engineering, and mathematics with art education. Analyzing two decades of studies, they found that intentionally designed outdoor settings offer rich "STEAM learning affordances" for young children. Diverse natural elements encourage a spectrum of scientific and mathematical behaviors; for example, sand play invites children to experiment with forces, textures, and material properties (by pouring, molding, and observing cause-and-effect), while gardening in a plant-rich area prompts children to ask questions about living things, engage in hands-on observation, and even collect data to engage in authentic scientific practices. These informal outdoor explorations nurture skills such as problem-solving, classification, measuring, and noticing patterns in nature, all of which are foundational to science and engineering thinking. The findings underline the role of environment design in prompting STEAM skills and call for collaboration between educators and landscape architects. The overall implication is that teacher education should include increasing awareness of environmental affordances and integrating place-sensitive science pedagogies.

Collaborations within a larger educational community, engaging families and informal science resources, presents another way forward for early science education. In their work, Young, Hoisington, Kook, and Ramer (Young et al., 2024) describe the SISTEM project, a multi-faceted intervention for preschool educators and families of emergent multilingual learners (EMLs) in the U.S. The project has a strong focus on community and family engagement and includes professional learning, family science nights, STEM kits, and community engagement through informal science learning environments. A quasi-experimental design showed gains in teacher confidence and quality of instruction, while interviews with caregivers revealed increased science-related interactions at home, with these findings reinforcing the power of community-based approaches and the call for teacher education to build partnerships across formal and informal learning spaces.

4. Conclusions

Children arrive in educational settings with rich and often underappreciated conceptions about the world around them. These conceptions represent valuable starting points for learning. If we are truly interested in participatory learning as an approach that recognizes important competences in children, then it is essential that the voices of children are included in research. When teachers recognize and engage with these early scientific ideas, they can transform them into opportunities for conceptual development. Across diverse national and pedagogical contexts, the studies presented in this Special Issue advocate the need for policies and practices that enhance active, experiential, and meaningful science education from the earliest years of life and affirm that empowering young children in science education is crucial from both a pedagogical and scientific point of view. From this perspective, we have sought to bring together the main research directions by grouping them into subsections concerning children's ideas and voices, which cover teaching strategies and teachers' perspectives, including different forms of representations, contexts, and learning environments.

The findings of these studies emphasize that effective teaching strategies in early science education must embrace dialog, play, exploration, and guided inquiry, allowing children to experiment with ideas through observation, modeling, discussion, and reflection. Importantly, it is clear that young learners benefit when they are encouraged to express their thinking through multiple forms of representation, such as drawing, storytelling, embodied movement, symbolic play, and digital tools. These representational modes not only make children's thinking visible but also serve as scaffolds for the gradual articulation of more complex scientific ideas.

Teachers play a pivotal role in orchestrating these learning experiences. Their capacity to listen actively, pose thoughtful questions, and create safe spaces for inquiry is central to the empowerment of children. However, such responsiveness requires support, necessitating that teachers are also empowered through appropriate training to act as active facilitators of scientific thinking.

This Special Issue affirms that early childhood is a fertile ground for science learning and concept formation. From this perspective, a more holistic and participatory view of early science education emerges, not merely as a discipline to be mastered, but as a way of engaging with the world that is available to all children, from their earliest years. It values children as capable knowers, teachers as reflective co-learners, and science as a human endeavor rooted in curiosity, creativity, inquiry, and reasoning.

The review by Siry et al. (2023) reinforces these findings, underscoring the centrality of inquiry, play, affect, and inclusion in quality science education in early years education. Their synthesis of a decade of research outlines key future directions, including the need for multimodal methodologies, inclusive pedagogies, and increased attention to teacher education and policy frameworks. We share this vision and advocate for ECSE as a foundational and transformative part of lifelong science learning.

We hope that this issue provides not only a scholarly contribution but also an impetus for researchers, educators, and policymakers to continue building an early science education landscape that honors the voices, creativity, and potential of all young learners.

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References

Areljung, S. (2019). Why do teachers adopt or resist a pedagogical idea for teaching science in preschool? *International Journal of Early Years Education*, *27*(3), 238–253. [CrossRef]

Chen, S., Sermeno, R., Hodge, K., Murphy, S., Agenbroad, A., Schweitzer, A., Tsao, L. L., & Roe, A. J. (2024). Young children's self-regulated learning benefited from a metacognition-driven science education intervention for early childhood teachers. *Education Sciences*, *14*(6), 565. [CrossRef]

Christodoulakis, N., & Adbo, K. (2024). Exploring the emergence of chemistry in preschool education: A qualitative perspective. *Education Sciences*, *14*(9), 1033. [CrossRef]

Clark, A., & Flewitt, R. (2020). The competent child: Valuing all young children as knowledgeable commentators on their own lives. *Review of Science, Mathematics and ICT Education*, *14*(2), 9–24.

Clark, A., & Moss, P. (2001). *Listening to young children: The Mosaic approach*. National Children's Bureau for the Joseph Rowntree Foundation.

Clark, A., & Moss, P. (2005). *Spaces to play: More listening to young children using the Mosaic approach*. National Children's Bureau.

Eshach, H., & Fried, M. N. (2005). Should science be taught in early childhood? *Journal of Science Education and Technology*, *14*(3), 315–336. [CrossRef]

Fridberg, M., & Redfors, A. (2024). Thematic teaching of augmented reality and education for sustainable development in preschool—The importance of 'place'. *Education Sciences*, *14*(7), 719. [CrossRef]

García-Rodeja, I., Barros, S., & Sesto, V. (2024). Inquiry-based activities with woodlice in early childhood education. *Education Sciences*, *14*(7), 710. [CrossRef]

Hedegaard, M., & Fleer, M. (2008). *Studying children: A cultural-historical approach*. Open University Press.

Hedges, H., & Cullen, J. (2012). Participatory learning theories: A framework for early childhood pedagogy. *Early Child Development and Care*, *182*(7), 921–940. [CrossRef]

Ioannou, M., Kaliampos, G., & Ravanis, K. (2024). Condensation and precipitation of water vapor: The emergence of a precursor model through the engineering design process. *Education Sciences*, *14*(7), 757. [CrossRef]

Jelinek, J. A. (2024). From the spherical earth model to the globe: The effectiveness of a planetary model-building intervention. *Education Sciences*, *14*(7), 761. [CrossRef]

Kampeza, M., & Delserieys, A. (2020). Acknowledging drawing as a mediating system for young children's ideas concerning change of state of matter. *Review of Science, Mathematics and ICT Education*, *14*(1), 105–124.

Kampeza, M., & Delserieys Pedregosa, A. (2024). Symbolic representation of young children in science: Insights into preschoolers' drawings of change of state of matter. *Education Sciences*, *14*(10), 1080. [CrossRef]

Pahl, A., & Tschiesner, R. (2024). Teaching topic preferences in the nature–human–society subject: How trainee teachers justify their likes and dislikes. *Education Sciences*, *14*(11), 1184. [CrossRef]

Papantonis Stajcic, M., Vidal Carulla, C., & Åkerblom, A. (2024). Preschool class children and grade one pupils' questions about molecules from a digital interactive session at a culture center in Sweden. *Education Sciences*, *14*(6), 651. [CrossRef]

Ravanis, K. (2017). Early childhood science education: State of the art and new perspectives. *Journal of Baltic Science Education*, *16*(3), 284–288. [CrossRef]

Ravanis, K. (2022). Research trends and development perspectives in early childhood science education: An overview. *Education Sciences*, *12*(7), 456. [CrossRef]

Rogoff, B. (2008). Observing sociocultural activity on three planes: Participatory appropriation, guided participation, and apprenticeship. In K. Hall, P. Murphy, & J. Soler (Eds.), *Pedagogy and practice: Culture and identities* (pp. 58–74). Sage.

Salmon, A. K. (2016). Learning by thinking during play: The power of reflection to aid performance. *Early Child Development and Care*, *186*(3), 480–496. [CrossRef]

Siry, C., Cabe-Trundle, K., & Sackes, M. (2023). Science education during the early childhood years: Research themes and future directions. In N. Lederman, D. Zeidler, & J. Lederman (Eds.), *Handbook of research on science education* (Vol. III). Routledge.

Trina, N. A., Monsur, M., Cosco, N., Shine, S., Loon, L., & Mastergeorge, A. (2024). How do nature-based outdoor learning environments affect preschoolers' STEAM concept formation? A scoping review. *Education Sciences*, *14*(6), 627. [CrossRef]

Vartiainen, J., & Kumpulainen, K. (2020). Playing with science: Manifestation of scientific play in early science inquiry. *European Early Childhood Education Research Journal*, *28*(4), 490–503. [CrossRef]

Young, J. M., Hoisington, C., Kook, J. F., & Ramer, M. (2024). Powering up preschool science: A home–school–community partnership to support science learning with a focus on emergent multilingual learners. *Education Sciences*, *14*(7), 785. [CrossRef]

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Article

Exploring the Emergence of Chemistry in Preschool Education: A Qualitative Perspective

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Abstract: The objective of this study was to deepen our comprehension of how children develop understanding in the field of science, particularly in chemistry. Using the framework theory as a theoretical lens enabled a focus on emergence as a dynamic change and transition. According to the framework theory, children's science learning involves a wide range of intuitive and counterintuitive scientific concepts related to ontological and epistemological perspectives. How children transition from everyday to scientific thinking during their early years of education is influenced by ontological and epistemological stances. The objective of this study is to introduce science content—including chemical concepts to preschool children—by utilizing a play-based learning approach in a longitudinal study. The exploration of verbal and non-verbal material, specifically pertaining to chemical content and individual differences, involved implementing educational experiments and real-life or animated zooming-in videos. The results indicated a well-established physical ontological framework utilized for the systematic interpretation of submicroscopic phenomena.

Keywords: chemistry; preschool; didactics

1. Introduction

In the past decade, there has been a growing emphasis on incorporating natural science into preschool education. Both educational researchers and practitioners have shown increased interest in using play-based learning and conceptual play to introduce science concepts. This early exposure to science offers numerous benefits. Firstly, high-quality preschool education is widely recognized as crucial for future academic success [1]. The preschool years also have the potential to shape lifelong learning and are seen as an important part of our cultural heritage [2], making this period an integral aspect of education. Science education in preschool settings serves not only the goal of teaching science but also contributes to various developmental domains. It helps foster social development [3], lays the foundation for language and conceptual understanding [4–10], enhances motor skills [3], and supports problem-solving abilities [11,12]. Additionally, there are equity goals in science education that aim to empower children with knowledge and enable them to make informed decisions for a sustainable society [13]. Early exposure to science also aims to create positive associations with the subject, catering to children's curiosity and fostering their interest and positive attitudes toward science in their early education [14–19]. These positive associations are considered crucial not only for future formal learning but also for later informal science education [20].

1.1. Chemistry in Preschool

Research studies in natural science didactics have primarily focused on the fields of physics and biology. This is because phenomena within these subjects are naturally embedded in children's everyday lives and easily pique their curiosity. Many biological and physical phenomena can be directly experienced, and their causes can often be deduced and predicted. However, chemistry faces a unique challenge as it offers a relatively limited number of everyday encounters, which are not always apparent. Furthermore, understanding the causes behind chemical phenomena is not easily attainable. While some chemical transformations, like phase transitions and combustions, can be experienced, many ongoing processes are so slow that they are difficult to witness, such as the transportation of matter through natural cycles. One practical way to experience chemistry is in the kitchen, where activities like mixing, stirring, dissolving, and tasting provide opportunities to explore chemical phenomena. Unfortunately, the scientific explanation behind these processes, or the reasons behind chemical phenomena, are often ignored or too abstract to explain. This is mainly because understanding these explanations requires comprehending submicroscopic particles and their relative size. In fact, size is a key factor in understanding chemistry. This project investigates how children develop the concept of smallness.

How can we describe the sizes of submicroscopic particles? Since there is no specific language to describe them, the scale of a femtometer (the radius of an atomic nucleus) can only be understood in relation to something else. Unfortunately, the objects we use to determine size quickly become insignificant because we have no real experience with their actual size. If we use numbers to explain the atomic size, most scientific textbooks typically refer to the radii of neutral atoms, considered in their relative isolation. These typically range between 30 and 300 pm (trillionths of a meter). The radii of neutral atoms can also be measured in ångströms, which is a unit for measuring the length of submicroscopic entities. The radii of neutral atoms are between 0.3 and 3 ångströms (10^{-10} m). This means that the radius of an atom is more than 10,000 times larger than its nucleus [21]. If one cannot fathom the magnitude of 30 trillionths of a meter or something 10,000 times smaller than an atom, numbers quickly become devoid of their true significance. However, the general understanding that atoms are incredibly minuscule is usually enough to grasp most chemical concepts.

Teaching the concept of smallness, as mentioned before, is challenging. Similarly, understanding how we grasp the idea of smallness becomes equally difficult when we rely on our everyday language, which predominantly focuses on macroscopic objects. Describing something as small can be achieved by comparing it to other tiny items, like being smaller than an ant. Alternatively, we can convey the idea by emphasizing that these things are so minuscule that they exist within everything. Another approach is to use intensifiers such as "very small" or, for instance, repeatedly emphasizing the word "tiny" like "tiny, tiny, tiny little ones".

When asking children what the smallest thing imaginable is, the answers may well be "insect babies". A grain of sugar viewed through a microscope becomes "dust" and toadstools become "fish". When a magnifying glass is used to look at a grain of salt amplifying its size, children might describe it as an ice block. This provides some indication about how size is perceived, with the result that the magnifying glass is seen as an item that makes things large instead of as a way to explore small things. When children imagine what something really small looks like, it often results in representations of continuous matter, where they simply see the smaller parts as smaller pieces of the item at hand [22]. In fact, research suggests that children's sub-microscopic perception can be enhanced with the aid of visual experience that supports their imagination [23]. This previous experience aids their imagination by providing a much firmer basis. The focus of this study is to examine how young children learn the concept of smallness when visual experience is provided and to explore the broader consequences of this learning on their understanding of natural phenomena, like evaporation.

1.2. Conceptual Development and Emergent Science

The process of learning scientific concepts has been extensively studied and is considered a transition from everyday concepts to formally introduced scientific concepts. Intuitive concepts, which are synonymous with everyday concepts, often originate from children's sense-based observations of their surrounding environment. Through the impact of education, intuitive ideas are influenced by formally introduced concepts. This transition involves expanding the content of concepts and incorporating scientific ideas, all within the context of language and the child's surrounding culture [24]. This progression is referred to as "emergent science" at the preschool level. Understanding how formally learned knowledge and intuitive ideas interact provides insights into the learning progression [25]. Emergent science emphasizes children's personal reflections regarding science, without assessing the accuracy of children's concepts from a strictly scientific standpoint. The emphasis is on the actual process of subject-specific learning. The development of scientific progress depends on various factors, including individual stances and sociocultural characteristics. Motivations, emotional connections, and interests are crucial elements in acquiring knowledge and learning.

Framework Theory

The analysis of the actual changes in emerging science can be approached from different perspectives. In this case, the framework theory is utilized to examine the development of children's understanding of science. The term "emerging science" is employed to emphasize the focus on the process of change. According to the framework theory, scientific learning arises from intuitive experiences in our everyday lives, which are primarily based on sense-based observations. These intuitive concepts are not separate entities but rather interconnected within frameworks and models that encompass ontological and epistemological concepts. Ontology involves our interpretations of the fundamental nature of reality, while epistemology pertains to our interpretations of the causal mechanisms used to explain a phenomenon. An example of the interrelation between an intuitive concept and its ontological and epistemological aspects can be observed in how children perceive the Earth and its connection to the intuitive concept of up/down gravity. When children are asked to draw the planet, the result is often various interpretations, as depicted in Figure 1.

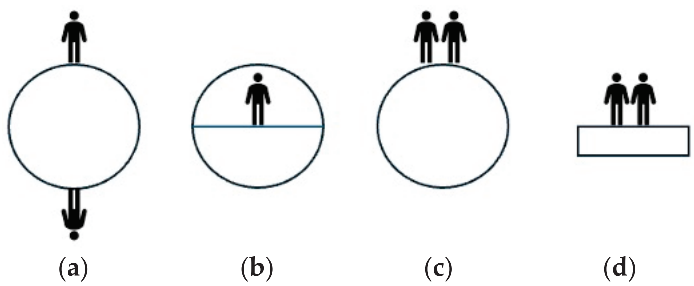

Figure 1. Some examples of children viewing the Earth as an object with up/down gravity; (**a**) people live on a ball-shaped Earth, (**b**) people live on flat parts of the Earth, (**c**) people live on top of the ball-shaped Earth, (**d**) people live on a flat Earth [26].

Research on children's initial ontology is an ongoing discussion, with researchers making different proposals regarding the number of initial ontological groups [27–30]. Table 1 presents one of these proposals, which states that children's early ontology is distinguished by four main ontological frameworks. In the psychological framework, the cause of an object's change is attributed to intentionality, whereas numbers and words are categorized as two separate elements of reality.

Table 1. Examples of early ontological and epistemological stances included in intuitive models [28].

Ontological Framework	**Ontological Stances**
Objects	Physical/up/down gravity
Animate entities	Psychological/animism
Numbers	Numbers/mathematical/discrete numbers
Lexical items	Lexical items/language

Introducing scientific concepts in a formal manner poses a challenge for children as they try to reconcile their sensory-based ideas with more abstract explanations of their surrounding phenomena. This procedure stimulates broader tectonic shifts in the epistemic and ontological principles of children [31]. As children commence their acquisition of scientific knowledge, the development of synthetic models becomes apparent. These models are a creative blend of intuitive and counterintuitive concepts (see Figure 2 and Table 2). In the framework theory, this change can be described as a progression from intuitive models to synthetic models and eventually to scientific models.

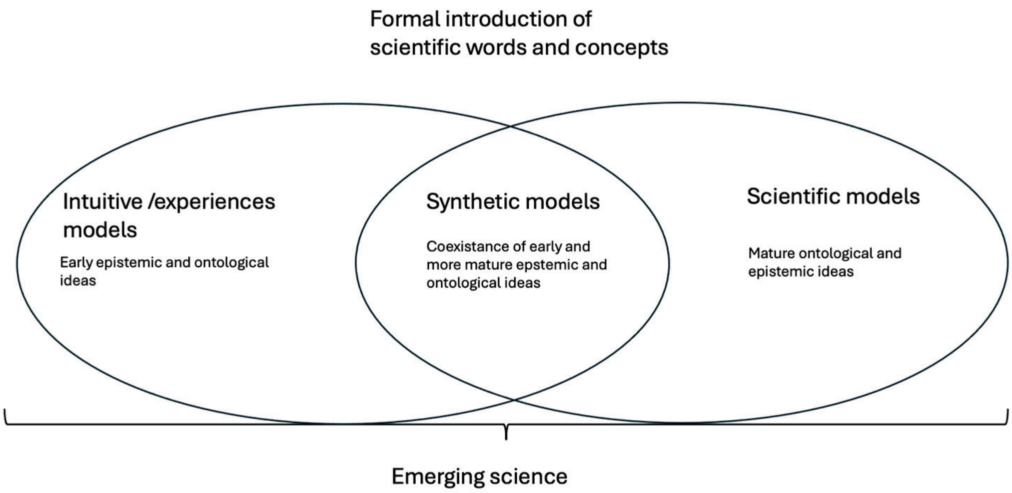

Figure 2. A summary of development from the aspects of the framework theory.

Table 2. Definitions of core concepts in the framework theory.

Concept	Concepts are the ways in which children understand and perceive processes or objects. There are two types of concepts: intuitive concepts and counter-intuitive concepts. Intuitive concepts are based in a child's immediate experiences and sensory input, and they are characterized by a basic level of knowledge and understanding. On the other hand, counter-intuitive concepts are acquired through education and go beyond direct sensory input. They involve more intrinsic characteristics that cannot be directly perceived.
Model	A child's complte comprehension of a process involves a culmination of concepts and the epistemology and ontological principles they employ to explain a phenomenon. Synthetic models, on the other hand, combine intuitive and counter-ontutivie concepts, as well as early and mature epistemic and ontoltogical skills. Finally, scientific models incorporate counter-intuitive concepts along with mature epistemic and ontological skills.
Ontology	A term used to describe a collection of broader concepts regarding the fundamental nature of reality. These concepts work together to categorize and organize our understanding of the world into groups of objects and processes. For instance, physical ontology focuses on the characteristcs of everyday-physical objects and their proceseses, while psychological ontology views processes as living entities. The capacity to critically analyze and reconstruct our existing ontological understanding based on new information is considered a more advanced ontological skill.
Epistemology	Epistemology pertains to the mechanisms that cause us to know and undersand a phenomenon. An initial skill in the realm of knowledge is the inclination to associate things with their external appearance. On the other hand, mature epistemic skills are demostranted by the capacity to generate various representations, question and assess one's own abilities and knowledge, and also evaluate those of others.

Considerable research has been undertaken on subject-specific learning, and the findings support that initial intuitive concepts are rooted in sensory experiences and vary in their development, depending on the learner and the topic being studied. Moving from intuitive to synthetic models represents both the specific learning pathway in a scientific field and scientific emergence in general. Various learning pathways have been proposed for different scientific subjects as well as for the scientific process itself. One such pathway involves systematic observations that start with the connection between the body and the five senses and then progress toward making predictions, and finally the verification of those predictions [30,32]. This particular learning pathway can serve as a useful tool for moving away from intuitive explanations and toward scientific concepts, including changes in epistemology and ontology [33]. These findings highlight the importance of engaging in scientific activities, acquiring scientific vocabulary, and enabling children to express different aspects of scientific explanations. The developmental process must allow for transferability across different contexts and extended periods of time [30]. This conclusion applies to the development of all subject-specific concepts.

1.3. Emerging Chemistry

There have been suggestions regarding learning pathways or trajectories for various chemistry topics, such as matter or the water cycle. At a broad level, understanding the fundamental aspects of matter involves understanding: (a) structure and composition; (b) physical properties and change; (c) chemical reactions; and (d) conservation [34]. A 2013 study outlined an overarching learning progression for the concept of matter, suggesting that children initially have a continuous understanding of matter, with no identification of its submicroscopic structure. Considering their exposure to education, children afterward reach an intermediate stage in which they recognize the presence of particles but project them with macroscopic attributes, for example, believing that the tiniest parts of a substance hold all of its macroscopic properties such as taste and color [35]. Finally, children recognize that particles make up the substance without displaying macroscopic properties. In this discussion, we will explore the first step in greater detail: particles existing within the continuous substance.

Research findings on children's understanding of chemical concepts align with the framework theory, emphasizing the importance of sensory-based intuitive concepts. Matter is deeply ingrained in individuals' lived experiences, and certain research suggests that children's ideas about the environment are implicit and unquestioned [36,37].

Research studies show that initially, children tend to categorize solid matter based on sensory-motor aspects like color, shininess, and softness [38]. These aspects are also connected to everyday generalizations, such as the belief that a hard, smooth, and transparent object will break when dropped. This sensory-based perception views matter as static, continuous, and uniform, with no empty space between particles, and its identity remains constant [39]. This leads to the conclusion that when an object changes appearance, it does not transform into a different form, but a completely different entity appears. In other words, there is no concept of transformation of matter.

An object's initial, external characteristics, like its boundedness, solidity, and enduring and distinct properties and functions, become the basis of its identification [40]. Other intuitive concepts related to the properties of matter include mass, volume, and weight, with weight being evaluated based on the feeling of heaviness, while length and volume are assessed based on size. These assumptions lead to the association of mass, volume, and weight only with large and visible objects. Simultaneously, objects of small size, like a small piece of plasticine, are not perceived as having mass, volume, or weight [41,42]. The attribute of solidity for objects is determined using everyday criteria such as hardness, durability, and resistance to cracking [43]. Additional challenges arise in children's identification of atypical solids such as dust, powders, or pliable and brittle materials [44].

The different states of matter represent one part of chemistry that can be experienced and defined on a macroscopic level using shape and volume. If a solid object is placed in a container, it maintains its shape and volume. If a liquid is placed in a container, it maintains its volume but assumes the shape of the container. If a gas is placed in a container, it assumes the volume and shape of the container. By following the observable general features of the different states of matter, children start to acquire stable signs as a way to identify or distinguish between the different states.

Similarly, appearance and actions such as spillability, colorlessness, and odorlessness [45] are used as properties to identify liquids. The most common liquid is water, and it can easily become a prototype for all kinds of liquids, due to liquids having external similarity. This conclusion is further supported by results that show that viscous liquids are not classified as liquids, because they do not appear like water. The gaseous state is a state that is not easily visualized and is often seen as non-material [41,42], resulting in the notion that liquids vanish during evaporation. The gaseous state is often associated with various phenomena, including heat, electricity, and everyday gases like soda [46,47].

To gain a comprehensive understanding of matter, it is essential to explore the transitions between its different states. One particular aspect that has been extensively studied is the water cycle [48]. To grasp the water cycle, at this educational level, it is necessary to consider a few key concepts: the different states of matter (solid, liquid, and gas), as well as the phenomena of evaporation and condensation caused by heating or cooling and the conservation of water during these processes. In another study, four distinct intuitive concepts regarding evaporation were identified [49]. These include the notion that water simply disappears, the belief that water can penetrate either the floor or a solid object, or that water is scattered in the air.

Transitioning from everyday experiences to a more subject-specific chemical perspective necessitates specific modifications. This change involves shifting from a macroscopic, sense-based perspective of the world to a submicroscopic worldview. In a sub-microscopic perspective, the properties of objects are conceptualized based on their internal composition. This change is difficult for learners of all ages [47] as it includes epistemic changes, notably understanding an object through multiple representations [50]. Considering these findings, learning pathways for matter should commence from discovering a child's everyday world, with an emphasis on the identification of various forms of matter [35]. The correlation between properties and color or shininess implies that learning could be enhanced by recognizing differences in properties among samples of matter with similar colors and sizes. These actions could lead to a deeper understanding of the intrinsic and fundamental variations in matter. Research has shown that sensory-based perception plays a crucial role in supporting the imagination at the submicroscopic level. In particular, providing visual experiences can effectively bridge the gap between the macroscopic and submicroscopic levels of matter [23,51]. This is particularly important in encouraging the development of children's understanding of concepts in more abstract domains.

Research Questions

The objective of this study is to examine the fundamental principles of children's emergent chemistry, focusing specifically on their comprehension of the concepts of smallness and evaporation. Smallness was chosen because it represents one of the core aspects of chemical knowledge. Vaporization was also included in this study because the phase transition between the liquid and gaseous state reflects children's understanding of the transition between visual and non-visual matter. The first goal of this research was to examine the process by which children generate everyday, synthetic, and scientific models of these concepts.

2. Materials and Methods

The purpose of this study was to explore the fundamental principles of emergent chemistry in children, focusing specifically on their understanding of smallness and evaporation. The research design took the form of a longitudinal study, designed as an educational experiment [52]. The present educational experiments followed a cyclical pattern, where each activity was promptly analyzed, and the resulting analysis served as the basis for planning the next activity. The activities were specially designed as play-based learning interventions. These play-based learning activities were carefully tailored to match the individual interests of the children, encouraging their ongoing engagement in the educational process [53]. In this way, scientific concept formation became a deliberate and thoughtful process led by the early childhood teacher [54]. Play-based learning environments both challenge children's broader understanding of the world and facilitate their acquisition of scientific knowledge. Other important aspects of this learning context include intersubjectivity and sustained shared thinking. Sustained shared thinking refers to an extended situation where the educator and the children engage in shared understanding and discourse [25].

2.1. Design of Activities

The interventions implemented in the play-based approach consisted of experimental activities and real-life or animated zooming-in videos, enabling children to grasp fundamental chemical concepts through play (See Table 3). The primary theme of the first five activities revolved around the concept of smallness and the last two revolved around evaporation. A detailed record of the activities was documented, and individual recall interviews were conducted to explore each child's understanding. The collected data were analyzed, with a specific focus on the children's conversations, body language, and gestures, in order to gain a deeper understanding of their engagement with the activity content.

The preschool environment in Greece is currently undergoing a transformation, incorporating contemporary educational practices and drawing inspiration from international experiences. The latest Greek curriculum outlines the essential abilities, skills, and attitudes that children should acquire upon completing their preschool education. This includes the field of natural sciences, which involves understanding living organisms and the properties of matter, as well as studying the Earth, space, and planetary systems. Instructions should be structured around everyday occurrences to facilitate exploratory inquiries on these topics. Specifically, teachers should support children in asking appropriate questions for investigation and encourage them to use their imagination and creativity to conduct experiments and acquire new knowledge.

Table 3. Description and time frame of the activities.

Meeting	Description of Activities
1–19 November	The researcher immersed himself in the daily activities at the kindergarten to familiarize the children with his presence.
1st meeting: 22–27 November 2021	In this experiment, the children observed leaves with magnifying glasses. In the first part, they observed them with their eyes and then magnifying glasses were introduced.
2nd meeting: 29 November–3 December 2021	The children used magnifying glasses to observe sugar and salt.
3d meeting: 6–10 December 2021	In this meeting, the researcher introduced a computer to show animations that zoomed in from a macroscopic view to the submicroscopic particulate level. In these zoomed-in videos, the children observed an artificial leaf.
4th meeting: 31 January–4 March 2022	In this experimental study, children were provided with several boxes containing ants. The use of magnifying glasses aimed to examine their impact on the children's perceptions of smallness.

Table 3. *Cont.*

Meeting	Description of Activities
5th meeting: 21–24 March 2022	In this experiment, children watched three zooming-in videos and were asked to describe what they saw. The first video showed a transition from the macro level to the microorganism level. The second and third videos exhibited zoomed-in animations from macro-level water to submicroscopic molecular water.
6th meeting: 4–8 April 2022	Water vaporization during boiling. Water was placed into a bottle and the level of the liquid was recorded. Following that, the water was poured into a pot and subjected to boiling for a period of 5 min. The leftover water was emptied back into the original bottle. The children were asked what they thought happened and why there was less water in the bottle.
7th meeting: 26–29 April 2022	Subsequently, the previous activity was replicated, substituting water with juice. Although water vaporizes from the juice as well as from pure water, the choice of using juice was made since they have different colors and were perceived as separate liquids.

Data were collected in Greece from participants in two middle-class public schools. These students had limited exposure to natural science experiments and did not participate in any organized play-based learning programs with natural science materials. This study included five groups, each consisting of five children aged 5 to 6 years old. Each play session lasted 20–25 min. Video recordings were made to capture the interactions and communication within each group, and additional material was collected through individual interviews. Research ethics approvals were granted by both the university and the Greek Ministry of Education.

2.1.1. The Teacher's Role

The teacher/researcher adopted a scaffolding stance toward the children. This involved being supportive of questions while not providing definite answers but rather scaffolding the children's thinking process. This also included gradually providing less support as the children showed improvement. The notions of microbes and molecules were never introduced by the researcher.

2.1.2. Data Analysis

Data were analyzed in the following steps:

1. Data were collected.
2. Relevant vignettes (smallness in the first experiment and evaporation in the last two) were selected.
3. Key objects and topics that reflected children's ideas about smallness and evaporation were identified. For example, the leaf, the ants, and the magnifying glass were central objects that reflected these ideas. The question "What is the smallest thing you can imagine" serves as a paradigm for this topic. The vignettes were organized based on these key objects and topics.
4. Criteria to distinguish intuitive and counterintuitive conceptions regarding smallness and evaporation were formalized.
5. Intuitive and counterintuitive vignettes, as well as synthetic models of smallness and evaporation, were categorized
6. General characteristics of intuitive smallness, counterintuitive ideas about smallness, and synthetic models of smallness were analyzed.

The participation of children in the experiments sparked the emergence of concrete ideas regarding smallness and evaporation. These ideas were further examined and categorized as intuitive, synthetic, and scientific models, based on how the children conceptualized crucial materials and processes (see Table 4).

Table 4. A summary of the analytical basis for categorization into intuitive, counterintuitive, synthetic concepts, and scientific concepts.

Concept	Analytical Definition
Intuitive concepts	No presence of scientific fragments, sense-based understanding, expression of early epistemic skills, and ontological categorization, which suggests the emergence of a more differentiated definition.
Counterintuitive concepts	Presence of scientific fragments, mature epistemic skills, and specified vocabulary. Expressions of a differentiated or intuitive (physical or psychological) ontology.
Synthetic model	A creative synthesis of intuitive and counterintuitive concepts, reflecting a more holistic understanding of a process.
Scientific concept	Scientifically accepted explanations are characterized by mature ontological and epistemic ideas.

3. Results

3.1. Intuitive Model of Macroscopic Smallness

The focus of the first five activities was children's conceptualization of smallness, explored through how they made sense of the main objects in each activity. Characteristic examples of using these words were presented in the form of vignettes. The children's intuitive model of smallness was defined by its macroscopic characteristics. In other words, smallness only refers to visually accessible small things.

When children were asked what the smallest thing was, they typically provided a number of concrete objects, which were categorized as intuitive concepts. The tiniest conceivable entities were derived from objects that were readily observable, such as specks of dust, miniature LEGO pieces, ants, baby flies, turtles, stars, butterflies, snakes, snails, caterpillars, mice, camera lenses, bread crumbs, keys, and small buttons. Quite often, the children were oriented toward their immediate environment using their hands to portray or show something small or define smallness negatively, such as something that was not big.

Vignette 1

Researcher: *What would it look like if we cut them into very small pieces? If we close our little eyes and think of sugar being cut into little tiny little pieces, what do we get?*

Anastasis: *It will melt, melt, melt, melt if we do (he claps his hands as if to show he's melting the sugar) and then... gone.*

Athina: *If I do it too much like this with the knife (pretends to cut something with her hands) it will cut and it will become like a little tiny baby.*

Researcher: *Like a little baby, huh? What if we cut it even smaller?*

Marianna: It will get so much smaller (she puts her fingers together).

Children's comprehension of smallness was also articulated in terms of comparable objects. When attempting to imagine microscopic aspects of salt and sugar, children would liken them to small balls, stones, small medicine, ants, snow, glass, or gold dust. In the two zooming-in sessions, the microscopic elements were reinterpreted as real physical objects such as animals or flowers. Water molecules were described as little spores, bubbles, stones, little balls of water, a Mickey Mouse head, a rabbit's, or a human head. Geometric vocabulary was also used, as the molecules were viewed as circles that were tied to each other. These vignettes were categorized as intuitive concepts.

In other words, children perceived the smaller particles of salt and sugar, as well as the real-life and animated elements in the zooming-in videos, and the water molecules, as concrete, real-life physical objects. Their identification of similarities between these objects illustrates that children observed a sense of commonality between the items. These objects are physical entities, exemplifying the application of a physical ontological framework. The usage of this framework may create barriers in trying to understand the counterintuitive properties of submicroscopic elements.

Moreover, less frequently encountered examples of smallness were exemplified in terms of depth. The children viewed the animated zooming-in videos as a journey into matter, with the progressively smaller levels being perceived as moving deeper in. A few vignettes defined smallness as an age category, suggesting that smaller ants are younger.

3.2. Synthetic Conceptions of Smallness: Invisibility Does Not Mean Non-Existence

Counterintuitive concepts of smallness were predominantly centered around the notion of the microbe. This notion functioned as a general category, which children used to represent all kinds of characteristics in relation to smallness. In meeting 1, parts of the leaves were defined as microbes. In meeting 3, the children used the same notion to describe the various forms and colors that they saw in the animated zooming-in video. The idea of a microbe was employed in an unspecified way, encompassing meanings such as exceedingly small elements or circles of very small sizes. In many instances, children reported that microbes were the fundamental components of various objects, suggesting that the world is made out of tiny, round entities that constitute all sorts of things. In these vignettes, microbes were perceived as being so small that they could only be viewed under a microscope. These counterintuitive ideas suggest the emergence of a synthetic model of smallness, in which things may exist, even though they cannot be seen with the eye. This model designates the emergence of an atomic, molecular perspective of the world.

As an example, the children described how a leaf, an orange, and dust would all appear to consist of microbes when observed under a microscope. Within the context of these vignettes, the children considered microbes to be of such diminutive proportions that their visibility could only be achieved through microscopic examination, thereby the children acknowledged the existence of microbes despite their invisibility to the naked eye. This finding represents a generalization of the zooming-in animation, in which the molecular structure of water was depicted as a model of little balls connected with lines. This emerging understanding of the microscopic level does not necessarily mean that children understand that all things are made of small particles, as children often interpret them as real physical objects.

In one vignette, a child reimagined the microscopic structure of a leaf that he saw in an animated zooming-in video as a fight between two sides—the illness-producing and curing elements. The child used his imagination to understand the microscopic level in a way that made sense to him.

The application of the notion of microbes is termed as counterintuitive because it includes the counterintuitive notion that things are made of really small elements, thus opposing the understanding of matter as continuous. Even though microbes were used to denote visually accessible small structures, their usage contributed to the emergence of a scientific perspective toward smallness.

Vignette 2

Anastasia: *That they are some tiny little creatures.*

Researcher: *Some tiny little things... And what are these tiny little things? What do they look like?*

Areti: *Microbes.*

Researcher: *And what do they look like?*

Anna: *There is a so and so (forms a circle in the air); there is a so and so and so and so microbe (draws it in the air).*

Researcher: *Show the group.*

Anna *(makes circles with her hand in the air): One like this, one like this, one like this, and one like this, many many, many, and circles and like this...*

Researcher: *No, you don't have to. Well, tell us what we saw in the videos.*

Areti: *Microbes, just microbes.*

Anna: *I had seen some microbes that were making some sounds; there were so many of them in the leaf... They were such little circles, little circles, little circles.*

Researcher: *Have you ever seen something so small before?*

Anna *and Areti: No.*

Researcher: *Is this the first time you've seen it?*

Anastasia: *I saw it.*

Researcher: *What did you see?*

Anastasia: *I saw some small, very small things that I saw... round... I saw inside there in the tree... Those round things were ants... No, they weren't ants... They were microbes.*

In counterintuitive concepts of salt and sugar, the children reported that cutting salt into small pieces would have made the small pieces invisible to the naked eye, but they could still exist. Similar conceptions were expressed with microorganisms, with children stating that objects were full of these small germs that could only be seen through the microscope. In counterintuitive concepts regarding the smallest thing that they could think of, some children acknowledged the existence of objects invisible to the eye, which they referred to as "very microscopic". They recognized that these objects exist at a great depth and appear different from the same objects at the macroscopic level. In a counterintuitive concept regarding ants, ants were understood as having nonvisible internal organs, like a heart and bones.

Vignette 3

Researcher: *Let me ask you. If this salt was cut into smaller pieces?*

Anastasis: *Yes.*

Researcher: *And we cut it so small that we couldn't see it, would there still be salt?*

Anastasis: *Yes.*

Researcher: *There would be, wouldn't there? I mean, is it possible for something to be so invisible to the eye but still exist?*

Anastasis: *Yes, but wouldn't we see it?*

Researcher: *What would it take for us to see it?*

Anastasis: Microscope.

In counterintuitive concepts related to water molecules, some children were able to generalize the idea that all objects consisted of imperceptible tiny spheres, similar to the ones depicted in the videos on water molecules. The concept highlighted in this idea indicates the emergence of the concept of molecules. Alongside this comprehension, several additional scientific fragments emerged, including the notion that these formations are held together through some forces. The usage of vocabulary such as "electrical current" or "microscopic laser" served to communicate the idea that the particles bonded together like tiny magnets. The same children also replicated other scientific fragments, such as the discovery that water maintains an identical atomic structure in all three forms, regardless of its external appearance. This indicates that scientific knowledge does not appear as a set of disparate fragments but as an interconnected network of concepts. In fact, the counterintuitive idea that matter's behavior relies on electrical currents can be more easily understood in the context of a molecular depiction of matter.

Vignette 4

Researcher: *Anna, do you remember what we did last week?*

Anna: *We watched some videos. There was something round that had made them, particles, and the current had joined them.*

Researcher: *The current had connected them? Okay, what were these balls that were connected to the current?*

Anna: *Particles.*

3.3. Intuitive Conceptions of Evaporation

Many children participating in the vaporization experiment perceived water, bubbles, fire, and smoke as distinct elements, failing to recognize their interconnectedness. Specifically, each element was perceived intuitively, for example, stating that "water is making some bouncing bubbles, that it is boiling, goes up and down and getting out, like a wave, was turning, was becoming white, appeared like milk, and that it made a strange sound". The bubbles were described as follows: some little white balls, rumbling water, shampoo, some oil, a hole (which) opens in the water, and growing water. They also used the metaphors of a pool, a whirlpool, a tornado, and a volcano. The water vapor above the surface was not seen as a result of water condensation, but instead, it was identified as smoke produced by the stove.

The boiling water was also treated intuitively as a physical object. More specifically, the children often stated that the decreasing water level was attributed to the water going more down, or that it became shorter, moved toward the bottom, or became smaller and smaller, like any other physical object influenced by gravity. Another explanation provided was that it melted. Similar results were replicated with the juice, with the children stating that it went a little bit down, it was because it was boiled, it decreased, or even that it just disappeared. Another child described the process as 'the mass became smaller and little.' Another similar explanation was that 'the juice got stuck at the bottom of the pot'. In this set of vignettes, the zooming-in videos of the previous sessions, which introduced children to the submicroscopic world, did not contribute to these interpretations of evaporation. In other words, children did not use this knowledge as a basis for explaining the transformation of macroscopic water to vapor.

Some children predicted that heating water would make it 'bigger and longer', or that it would stay the same. These answers are not entirely unjustified as water expands when boiling. Nevertheless, they are still deemed as intuitive conceptions because they do not depict the counterintuitive phenomenon of the change of state, even though they are in accordance with the facts when water boils. Other children also said that the researcher cheated, by spilling or drinking it while the children were not looking. All of these ideas are defined by the macroscopic understanding of the liquid.

During individual interviews, children were asked to generalize their findings. Vignettes in which children were unable to generalize vaporization with other liquids were evaluated as everyday conceptions. For example, children reported that heated water would not create smoke or vapors or that the juice would catch fire. In one vignette, a child reported that if you leave some water in the sun, the effect would be that the water would become "much thinner". Also, in another vignette, children said that milk would not decrease, because it would not have bubbles. Findings demonstrated that the children had a combined set of intuitive ideas about the various aspects of the vaporization experiment.

3.4. Synthetic Models of Evaporation

In the synthetic model of vaporization through boiling, children managed to connect smoke with water and fire. Specifically, children started to understand that due to the thermal agent, water and juice became vapor. As the children realized that the vapor did not come from the fire, some children began to use more specific vocabulary, like steam, water vapor, or "cloud". It was also interesting to see how two different children were also reminded of the cycle of water and used it to understand the experiment. One child expressed a very good understanding of evaporation, using the correct terminology, being able to predict what would happen if the boiling continued, what would happen with the vapor, and understanding that the boiled water continued to exist as vapor. In this set of vignettes, the zooming-in videos functioned as a preparatory step, which helped children reinterpret the disappearance of water through its transformation into vapor. In one vignette, a child interpreted vaporization by understanding fire and air as forces of activeness; the child reported that the fire and air push the juice upward, making it go up, and that the fire made the juice turn into smoke.

In synthetic vignettes of evaporation, children correctly predicted that the water and juice would decrease after boiling; often, they were able to explain why this was so and use the correct specified vocabulary. In one vignette, a child said that boiling would lead to the removal of vapors, which resembles the macroscopic idea that vapors are physically removed. The notion of burned water was also codified in synthetic conceptions, in that it shows the possible function as an intuitive expression reflecting the emergence of the scientific concept. Some children were also capable of generalizing, stating that other things, such as juice or tea, or even saliva and milk, could evaporate.

4. Discussion

The comparison between intuitive and synthetic models of smallness reveals numerous concrete, specific, and metacognitive changes that occur in children's perception of the world. Intuitive concepts are largely characterized by macroscopic visual perception. The central objects of the experiments as well as the microscopic elements of the videos were perceived as tangible, physical objects. To give an example, in the zooming-in videos, the microscopic structures were regarded as physical entities. These children were limited to a visibly accessible representation of small objects and, thus, were not able to imagine that these objects also had submicroscopic structures.

In synthetic concepts, on the other hand, the children's notions of smallness recognized the existence of invisible things, which can be viewed with the help of the microscope. The non-differentiated application of the term "microbes" included the scientific emergence of smallness through various unspecified characteristics. These notions strongly depended on immediate visual characteristics, while at the same time functioning as the basis for cultivating the idea that even smaller elements, which are not visually accessible, might exist and be the building blocks for various objects. The focus on small, invisible things called microbes may have initially been caused by a focus on illness due to the COVID pandemic and then reinforced through the animated zooming-in videos that showed small, round things. Nonetheless, these findings show that the conceptual framework for a more scientific emergence of the concept of smallness—as something smaller than what we can see—is indeed possible for preschool children, and this finding opens up the potential for the emergence of various chemical phenomena if transferable to other relatable experiences.

The existence of frameworks seems to be confirmed by another set of observations as well. Data indicate that children who used the notion of microbes were able to conceptualize leaves as part of a biological system of interconnected functions or to understand the electromagnetic properties of submicroscopic particles. In this sense, learning science is not a process limiting itself to subject-specific representational changes, but rather existing within a range of interconnected representations that are relevant to it. This possibility is significant for the emergence of chemistry, as it allows children to develop a submicroscopic perception of the world.

When comparing intuitive and counterintuitive concepts of evaporation, similar patterns emerge. Initially, children struggle to connect the different components of evaporation, leading to explanations based on observation rather than on an understanding of the underlying phenomenon of water loss. Conversely, the defining feature of the synthetic model was the children's tendency to establish connections between the different elements of the experiment. The ability to create these connections represents a higher epistemic change toward understanding evaporation.

The present research identified a strong presence of the physical ontological framework where the children systematically interpreted submicroscopic elements as everyday physical objects. These data indicate that moving beyond a purely physical ontological framework is necessary to fully grasp the submicroscopic intricacies of the world. It is crucial to clarify that this does not imply the invalidation of the established principles governing physical objects; rather, it signifies a differentiation of the two ontological levels, shedding light on the behavior of submicroscopic constituents. As demonstrated by Vosniadou, a comparable phenomenon occurs in the comprehension of planets behaving distinctively from ordinary physical entities [55,56]. The results also indicated a prominent existence of a psychological framework among children and a tendency to interpret microscopic elements as living entities.

The analysis of the findings in both smallness and evaporation indicates a possible mutuality between the two conceptions. The scientific emergence of smallness is closely related to the understanding that non-visible objects, aspects, and traits exist. The children in the evaporation experiments made a similar discovery, leading them to the realization that water cannot disappear, but it exists in a different invisible form as vapor. By analyzing the interrelation between the different aspects of the experiments, the children arrived at an abstract result with no immediate concrete referents. This can be a guideline for how microscopic smallness generally emerges. Preschool-aged children who rely solely upon sensory observations often conclude that objects that are not visible no longer exist. But posing questions about everyday phenomena that cannot be answered through their immediate senses is a process that may lead them to unexpected results regarding the nature of their surrounding world. This process is also reflected in the cultivation of reasoning skills, like metacognition, which plays a crucial role in emergent science.

One limitation of the present study is the decision not to include any statistical analysis of the data. As a result, the findings have an indicative character, mainly aiming to understand how intuitive and synthetic conceptualizations of smallness and evaporation might appear. Further analyses should be undertaken, aiming to provide more certain and generalizable data for the future. More importantly, understanding the extent and age-specificity of children's adoption of intuitive and counterintuitive ideas about smallness represents the next step for the current project.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Measures were taken to enable informed consent for children, parents, and teachers. The consent obtained included specific provisions for ensuring the anonymity of the children and the school, as well as the commitment to publish this study's results in research papers. The children's names were altered and no details about the school's whereabouts were given. The children were informed that participation in activities was optional and they had the choice to exit whenever they desired.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author due to privacy concerns.

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References

1. Makles, A.; Schneider, K. Extracurricular Educational Programs and School Readiness: Evidence from a Quasi-Experiment with Preschool Children. *Empir. Econ.* **2017**, *52*, 1181–1204. [CrossRef]
2. European Union Lifelong Learning Platform—European Civil Society for Education. Available online: http://lllplatform.eu/ (accessed on 10 December 2019).
3. Hedegaard, M.; Fleer, M. *Play, Learning, and Children's Development: Everyday Life in Families and Transition to School*, 1st ed.; Cambridge University Press: Cambridge, UK, 2013; ISBN 978-1-139-23674-4.
4. Akerblom, A.; Anderberg, E.; Alvegard, C.; Svensson, L. Awareness of Language Use in Conceptualization: A Study of Children's Understanding of Movement and Gravity. *Scand. J. Educ. Res.* **2011**, *55*, 255–271. [CrossRef]
5. Clements, D.H.; Sarama, J.; Germeroth, C. Learning Executive Function and Early Mathematics: Directions of Causal Relations. *Early Child. Res. Q.* **2016**, *36*, 79–90. [CrossRef]
6. Guo, Y.; Liu, Y.; Oerlemans, A.; Lao, S.; Wu, S.; Lew, M.S. Deep Learning for Visual Understanding: A Review. *Neurocomputing* **2016**, *187*, 27–48. [CrossRef]
7. Henrichs, L.F.; Leseman, P.P.M. Early Science Instruction and Academic Language Development Can Go Hand in Hand. The Promising Effects of a Low-Intensity Teacher-Focused Intervention. *Int. J. Sci. Educ.* **2014**, *36*, 2978–2995. [CrossRef]
8. Menninga, A. *Language and Science in Young Learners: Intervening in the Balance between Challenging and Adapting*; Rijksuniversiteit Groningen: Groningen, The Netherlands, 2017; ISBN 978-90-367-9910-2.
9. Parsons, A.W.; Bryant, C.L. Deepening Kindergarteners' Science Vocabulary: A Design Study. *J. Educ. Res.* **2016**, *109*, 375–390. [CrossRef]
10. Spycher, P. Learning Academic Language through Science in Two Linguistically Diverse Kindergarten Classes. *Elem. Sch. J.* **2009**, *109*, 359–379. [CrossRef]
11. Conezio, K.; French, L. Science in the Preschool Classroom—Capitalizing on Children's Fascination with the Everyday World to Foster Language and Literacy Development. *Young Child.* **2002**, *57*, 12–18.
12. Flannagan, J.S.; Rockenbaugh, L. Curiosity + Kindergarten = Future Scientists. *Sci. Child.* **2010**, *48*, 28–31.
13. Caiman, C.; Lundegård, I. Pre-School Childrens Agency in Learning for Sustainable Development. *Environ. Educ. Res.* **2014**, *20*, 437–459. [CrossRef]
14. Eshach, H.; Fried, M.N. Should Science Be Taught in Early Childhood? *J. Sci. Educ. Technol.* **2005**, *14*, 315–336. [CrossRef]
15. Baruch, Y.K.; Spektor-Levy, O.; Mashal, N. Pre-Schoolers' Verbal and Behavioral Responses as Indicators of Attitudes and Scientific Curiosity. *Int. J. Sci. Math. Educ.* **2016**, *14*, 125–148. [CrossRef]
16. Ferreira, J.A.; Paiva, J.; Grande, C. Hands-on Chemistry in Preschool Education: Experiments Executed by Little "Scientists" in Kindergarten. *Comunicacoes* **2017**, *24*, 99–112.
17. Mantzicopoulos, P.; Patrick, H.; Samarapungavan, A. Young Children's Motivational Beliefs about Learning Science. *Early Child. Res. Q.* **2008**, *23*, 378–394. [CrossRef]
18. Pattison, S.A.; Dierking, L.D. Early Childhood Science Interest Development: Variation in Interest Patterns and Parent–Child Interactions among Low-income Families. *Sci. Educ.* **2019**, *103*, 362–388. [CrossRef]
19. Ummanel, A. Metaphorical Perceptions of Preschool, Elementary and Secondary School Children About Science and Mathematics. *EURASIA J. Math. Sci. Tech. Ed.* **2017**, *13*, 4651–4668. [CrossRef]
20. Alexander, J.M.; Johnson, K.E.; Kelley, K. Longitudinal Analysis of the Relations between Opportunities to Learn about Science and the Development of Interests Related to Science. *Sci. Ed.* **2012**, *96*, 763–786. [CrossRef]
21. Greenwood, N.N.; Earnshaw, A. *Chemistry of the Elements*, 2nd ed.; Butterworth-Heinemann: Oxford, UK; Boston, MA, USA, 1997; ISBN 978-0-7506-3365-9.
22. Carey, S. Science Education as Conceptual Change. *J. Appl. Dev. Psychol.* **2000**, *21*, 13–19. [CrossRef]
23. Adbo, K.; Vidal Carulla, C. Learning About Science in Preschool: Play-Based Activities to Support Children's Understanding of Chemistry Concepts. *Int. J. Early Child.* **2020**, *52*, 17–35. [CrossRef]
24. Fleer, M. How Preschools Environments Afford Science Learning. In *A Cultural-Historical Study of Children Learning Science: Foregrounding Affective Imagination in Play-Based Settings*; Cultural Studies of Science Education; Fleer, M., Pramling, N., Eds.; Springer: Dordrecht, The Netherlands, 2015; pp. 23–37. ISBN 978-94-017-9370-4.
25. Siraj-Blatchford, I. Conceptualising Progression in the Pedagogy of Play and Sustained Shared Thinking in Early Childhood Education: A Vygotskian Perspective. *Educ. Child Psychol.* **2009**, *26*, 77–89. [CrossRef]
26. Sneider, G.; Pulos, S. Children's Cosmographies: Understanding the Earth's Shape and Gravity. *Sci. Educ.* **1983**, *67*, 205–221. [CrossRef]
27. Baillargeon, R.; Stavans, M.; Wu, D.; Gertner, Y.; Setoh, P.; Kittredge, A.K.; Bernard, A. Object Individuation and Physical Reasoning in Infancy: An Integrative Account. *Lang. Learn. Dev.* **2012**, *8*, 4–46. [CrossRef] [PubMed]
28. Carey, S.; Spelke, E. Domain-Specific Knowledge and Conceptual Change. In *Mapping the Mind: Domain Specificity in Cognition and Culture*; Hirschfeld, L.A., Gelman, S.A., Eds.; Cambridge University Press: Cambridge, UK, 1994; pp. 169–200. ISBN 978-0-521-42993-1.
29. Gelman, R.; Spelke, E.S.; Meck, E. What Preschoolers Know about Animate and Inanimate Objects. In *The Acquisition of Symbolic Skills*; Rogers, D., Sloboda, J.A., Eds.; Springer: Boston, MA, USA, 1983; pp. 297–326. ISBN 978-1-4613-3724-9.
30. Gelman, S.A. Psychological Essentialism in Children. *Trends Cogn. Sci.* **2004**, *8*, 404–409. [CrossRef] [PubMed]

31. Vosniadou, S. (Ed.) *International Handbook of Research on Conceptual Change*, 2nd ed.; Routledge: New York, NY, USA, 2013; ISBN 978-0-203-15447-2.
32. Brennan, M. Reflect, 'Refract' or Reveal: Sociocultural Explorations of the Place of Teacher Subjectivity in Infant Care. *Int. J. Early Years Educ.* **2017**, *25*, 156–170. [CrossRef]
33. Christodoulakis, N.; Adbo, K. An Analysis of the Development of Preschoolers' Natural Science Concepts from the Perspective of Framework Theory. *Educ. Sci.* **2024**, *14*, 126. [CrossRef]
34. Hadenfeldt, J.; Neumann, K.; Bernholt, S.; Liu, X.; Parchmann, I. Students' Progression in Understanding the Matter Concept. *J. Res. Sci. Teach.* **2016**, *53*, 683–708. [CrossRef]
35. Nakhleh, M.; Samarapungavan, A.; Saglam, Y. Middle School Students' Beliefs about Matter. *J. Res. Sci. Teach.* **2005**, *42*, 581–612. [CrossRef]
36. Johnson, D.W.; Johnson, R.T. Cooperative, Competitive, and Individualistic Learning Environments. In *International Guide to Student Achievement*; Routledge: London, UK, 2012; ISBN 978-0-203-85039-8.
37. Hellden, G. A Study of Core Development in Students' Conceptions of Some Key Ecological Processes. *Can. J. Sci. Math. Technol. Educ.* **2004**, *4*, 59–76. [CrossRef]
38. Smith, C.L.; Wiser, M. *Learning and Teaching about Matter in the Elementary Grades*; Routledge Handbooks Online: London, UK, 2013; ISBN 978-0-415-89882-9.
39. Kouka, A. Το νερό στη χημική εκπαίδευση: έννοιες, παρανοήσεις, δυσκολίες στην κατανόηση [Water in Chemical Education: Concepts, Misconceptions, Difficulties in Understanding]. Ph.D. Thesis, University of Ioannina, Ioannina, Greece, 2000.
40. Baillargeon, R. The Acquisition of Physical Knowledge in Infancy: A Summary in Eight Lessons. In *Blackwell Handbook of Childhood Cognitive Development*; Blackwell handbooks of developmental psychology; Blackwell Publishing: Malden, MA, USA, 2002; pp. 47–83. ISBN 978-0-631-21840-1.
41. Hatzinikita, V.; Koulaidis, V. Pupils' Ideas on Conservation during Changes in the State of Water. *Res. Sci. Technol. Educ.* **1997**, *15*, 53–70. [CrossRef]
42. Hatzinikita, V. Οι αναπαραστασεις των μαθητων του δημοτικου για τις μεταβολες της υλης. Ειδη, αιτιακες σχεσεις και μηχανισμοι. [The Representations of Primary School Students about the Changes of the Material. Species, Causal Relations and Mechanisms]. Ph.D. Thesis, University of Patras, Patras, Greece, 1995.
43. Johnson, P.; Tymms, P.; Roberts, S. *Assessing Students' Concept of a Substance*; Full research report; ESRC Society Today: Bath, UK, 2008.
44. Driver, R.; Asoko, H.; Leach, J.; Scott, P.; Mortimer, E. Constructing Scientific Knowledge in the Classroom. *Educ. Res.* **1994**, *23*, 5–12. [CrossRef]
45. Stavy, R.; Stachel, D. Children's Conception of Changes in the State of Matter: From Solid to Liquid. *Arch. Psychol.* **1985**, *53*, 331–344. [CrossRef]
46. Carey, S. Knowledge Acquisition: Enrichment or Conceptual Change. In *The Epigenesis of Mind: Essays on Biology and Cognition*; The Jean Piaget Symposium series; Lawrence Erlbaum Associates, Inc.: Hillsdale, NJ, USA, 1991; pp. 257–291. ISBN 0-8058-0438-2.
47. Gikopoulou, O. Changing Students' Perceptions of Matter through the Educational Model of Microcosm. *Int. J. Sci. Res.* **2017**, *6*, 848–855.
48. Fragkiadaki, G.; Fleer, M.; Ravanis, K. A Cultural-Historical Study of the Development of Children's Scientific Thinking about Clouds in Everyday Life. *Res. Sci. Educ.* **2019**, *49*, 1523–1545. [CrossRef]
49. Bar, V.; Galili, I. Stages of Children's Views about Evaporation. *Int. J. Sci. Educ.* **1994**, *16*, 157–174. [CrossRef]
50. Vosniadou, S.; Skopeliti, I. Conceptual Change from the Framework Theory Side of the Fence. *Sci. Educ.* **2014**, *23*, 1427–1445. [CrossRef]
51. Adbo, K.; Vidal Carulla, C. Designing Play-Based Learning Chemistry Activities in the Preschool Environment. *Chem. Educ. Res. Pract.* **2019**, *20*, 542–553. [CrossRef]
52. Hedegaard, M. Principles for Interpreting Research Protocols. In *Studying Children. A Cultural-Historical Approach*; Open University Press: New York, NY, USA, 2008; pp. 46–64.
53. Fleer, M. 'Conceptual Play': Foregrounding Imagination and Cognition during Concept Formation in Early Years Education. *Contemp. Issues Early Child.* **2011**, *12*, 224–240. [CrossRef]
54. Fleer, M.; Hedegaard, M. *Early Learning and Development: Cultural–Historical Concepts in Play*; Cambridge University Press: Cambridge, UK, 2010; ISBN 978-0-511-84483-6.
55. Vosniadou, S.; Skopeliti, I. Is It the Earth That Turns or the Sun That Goes behind the Mountains? Students' Misconceptions about the Day/Night Cycle after Reading a Science Text. *Int. J. Sci. Educ.* **2017**, *39*, 2027–2051. [CrossRef]
56. Vosniadou, S.; Brewer, W.F. Mental Models of the Earth: A Study of Conceptual Change in Childhood. *Cogn. Psychol.* **1992**, *24*, 535–585. [CrossRef]

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Article

From the Spherical Earth Model to the Globe: The Effectiveness of a Planetary Model-Building Intervention

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Abstract: The shape of the Earth is a fundamental concept that students need to learn in astronomy education. This paper reports the findings of a study that confirms the effectiveness of an intervention involving the construction of a model of the Earth prior to the introduction of the globe as a codified artefact. The educational intervention had been preceded by the EARTH2 test, which was used to check how well students participating in the study mastered the concept of the Earth's shape. The study included forty-seven primary school students (grades I and II). Effectiveness was measured by comparing the answers chosen by Polish children in a test as mental models. The study confirmed (A) that the intervention was effective: 49% of progressive changes, 30% of regressive changes, and 21% of changes within the same mental model were observed; (B) that there was an increase in the children's interest in space, revealed by an increased number of questions going far beyond the school astronomy curriculum; and (C) that students' concerns about the dangers of space were revealed. Key findings include the following: (a) Educational effectiveness regarding the concept of the shape of the Earth is achieved in activities that involve building a spherical Earth model before introducing a globe as a ready-made model. (b) The topics addressed in astronomy classes must be far broader than what the current curricula provide. They should take into account current issues reported by the media and deal with astronomical discoveries and space technology. (c) When organising activities, children's concerns about the dangers of space should be borne in mind.

Keywords: astronomy; Earth's shape; educational intervention; effectiveness; EARTH2 test

1. Introduction

When viewed in everyday life, the Earth appears flat. This impression has an enormous impact on the formation of the Earth's shape concept [1,2]. Since children are confronted with this image from the beginning of their lives, it becomes strongly embedded in their psyche, and they resort to it to explain natural phenomena [3,4]. The concept of the Earth's shape has a strong influence on the development of higher astronomical concepts, such as the day-and-night phenomenon [5,6]. Such concepts are referred to as threshold concepts because they are the gateway to a deeper understanding of science [7].

Research shows that it takes a long time before children start applying the concept of a spherical Earth to explain cosmic phenomena [8]. Such a long persistence of a misconception regarding the Earth is influenced, among other things, by cultural factors [9]. Appropriate educational support, on the other hand, causes children to adopt a spherical image of the Earth earlier. The effectiveness of educational interventions is confirmed as early as preschool [10–17].

Educational effectiveness is measured by establishing the difference between children's prior knowledge and their knowledge after the intervention. In the case of threshold concepts [7] (such as the Earth's shape concept), which serve as a lens for explaining natural phenomena [18], it is the degree to which a particular concept is embedded in a child's conceptual structure that can serve as a measure of educational effectiveness. The degree to which a concept is embedded in said structure can be established by checking whether the child applies the concept to explain natural phenomena. At the lowest level of grasping a concept, i.e., when integration in the structure is poor, a child simply replicates the response pattern. This is revealed when, when asked directly *what shape the Earth is*, the child directly answers *spherical*. However, when asked to explain other phenomena, they no longer refer to the Earth as a sphere. A higher degree of the concept's integration in the knowledge structure (also referred to as structuring) is revealed by those children who constantly refer to the spherical Earth when solving problems (e.g., in order to answer how people move on Earth). This issue is crucial when we talk about the contextualised use of the concept.

When examining the degree of structuring, we find that even many older students (10 years old) do not have a well-embedded concept of a spherical Earth [19]. To explain natural phenomena (the location and movement of people, the location of trees and clouds, the movement of a kicked ball, and the location of the sun at night), they abandon the concept of a spherical Earth. If the concept of a spherical Earth is not properly embedded, it can lead to difficulties in adopting more advanced astronomical concepts, such as the phenomenon of day and night [20–22]. For this reason, it is suggested that the concept of the Earth's shape should be supported at the beginning of the educational path [16].

This assumption is employed in the Polish preschool education and early school education systems. Despite these assumptions, the scope of science education (including astronomy) is severely limited. At the level of preschool education, children learn about the phenomena of day and night, the seasons, the phases of the Moon, and the Polish astronomer Nicolaus Copernicus. In the early grades of primary school (I–III), these contents of astronomy education are repeated. The concept of the Earth's shape, despite being a key concept [7], is only marginally present in the Polish education system. Teachers devote too little time to explaining the image of the spherical planet to children. Currently, the curriculum is being re-examined, and efforts are being made to modify it [19].

Forming the notion of a spherical Earth is difficult because it requires one to accept information that contradicts everyday observations. Hence, appropriate intervention is key [2,11–13,15,16,23]. Research shows that a teacher who introduces a globe to children without any prior explanation does not achieve the intended goal [4]. Children who are convinced that the Earth is flat have difficulty accepting a globe as a cosmological model of the Earth.

Research into the development of the Earth's shape concept suggests that a significant change in the conceptual structure is required. Such a change is referred to as reconstruction (accommodation, [24]), and it causes one to explain phenomena through a new lens (frame, [18,22,25–27]). When the spherical shape of the Earth is assimilated, it also forces a change in perceptions as to the location of people living on Earth and the way they move. Indeed, in their everyday experience, children live their lives "on a flat Earth". Accepting the notion that the Earth is a sphere forces them to address the question of whether people can live on the curvature of the planet and whether they can live on the other side of it. The same is true of the phenomenon of people moving across the sphere. These questions do not arise spontaneously but are the result of deeper reflection and do not necessarily reveal themselves in all children [3,9]. The realisation that people walking for days in one direction would arrive at the place where they started (a characteristic of the sphere) and that they would not fall off the Earth (gravity) is a nearly scientific explanation that requires a change in perspective and proper knowledge.

Conceptual change, broadly speaking, involves the gradual transfer of objects and phenomena visible on a daily basis, from a "flat" Earth to a "spherical" one. This mental "relocation" is a way of solving cognitive problems [2,19]. The shift is possible once the right information has been acquired and the right level of cognitive skills has been achieved to construct the right ideas [18,23]. Similarly, the phenomenon is elucidated by proponents of the precursor model theory [25]. They contend that for a child to comprehend a phenomenon, it is essential to construct appropriate cognitive frameworks [26]. The specific type of cognitive development required for a child to understand the Earth's spherical shape involves (a) recognising that the ground observed daily is part of a larger whole and (b) understanding that viewing the entire Earth necessitates a change in perspective (significant distancing from its surface).

1.1. Development of the Earth's Shape Concept

The process of integrating the Earth's shape concept into one's mental structure is described by the mental models theory by Stella Vosniadou and William Brewer [3,27]. The concept of mental models implies that children construct coherent ways of explaining phenomena. Ranging from initial models through synthetic models to scientific models, they chart a developmental pathway [19]. Regarding the Earth's shape, mental models are usually invoked in the context of secondary problems, such as the location and movement of people on Earth. Children coherently reveal their beliefs through statements, drawings, and plasticine creations. Due to their coherent nature, well-structured childlike logic, and their explanatory and predictive nature, such statements are considered to be close to theories. Initially, children locate people on a flat Earth [3,28]. In their drawings, they depict the Earth as a line of infinite length with the ground beneath it and draw people standing on that line. From the children's explanations and opinions, it appears that they are recounting a personal experience, i.e., the sight of people walking on the Earth. When given a lump of plasticine, they form a cuboid and stick human figurines in it as if they were standing on the Earth [19,29].

Children in whom the process of constructing the notion of a spherical Earth has already begun start explaining that people only live at the top of the planet and add that they cannot go any lower because they would fall off the Earth [3,30]. However, the imaginary edge of the Earth is not necessarily physical. In their explanations, they refer to psychological barriers, such as speaking another language [29]. Sometimes they further flatten the part of the sphere where people live [28]. On a piece of paper, they draw a circle representing the part of the Earth where people live seen from above. Using plasticine, they make a sphere, flatten it on one side, and stick a figurine there to mark the location of people [19].

Sometimes, when constructing the concept of sphericity, children explain that people live inside a hollow Earth (*hollow sphere model*, [3]). This representation confirms the spherical shape of the Earth and agrees with the statement that it is impossible to fall from the Earth (people are surrounded by Earth on all sides). They draw a circle on a piece of paper and locate people inside at the bottom of the circle. With a lump of plasticine, they try to create a sphere and, pointing to a hole, explain that people live inside it.

There are also children who depict two types of Earth in their drawings—one spherical and the other flat. They explain that the flat one represents what they see every day, while the other refers to what the teacher says when showing a globe (*dual Earth model*, [3]). Similar behaviour is observed in studies using plasticine. After building a globe, children claim that it is the Earth but different from the one they live on [29].

The development of the Earth's shape concept is linked to the concept of the location of clouds and the direction of rainfall. Research shows that before children adopt the idea that the clouds are located around the spherical Earth, they place them just above the flat Earth [3]. In drawings, they mark their location parallel to the line of the ground. As they start imagining the Earth as a sphere, they explain that clouds—like people—are only located at the top. The direction of rainfall seemed to correspond with their ideas about the direction of gravity.

1.2. Effective Structure of Interventions

Research on the effectiveness of educational interventions in changing children's beliefs about the shape of the Earth shows that they can be effective as early as preschool. A study of Greek children by Maria Kampeza and Konstantinos Ravanis [2] indicated that even a two-day educational activity that allowed children to experience the shape of the Earth can influence the formation of children's perceptions. The authors concluded that, already, preschool children are ready to accept the scientific idea of the shape of the Earth if only the activities are organised in an appropriate way. Based on the precursor model, they hypothesised that by understanding children's learning processes and cognitive development, it is possible to design appropriate activities during which engaged children would discover changes and, guided by the teacher, formulate conclusions similar to scientific ones [25,31–33].

The effectiveness of the intervention was confirmed in those activities where children were appropriately engaged in conversation [34], children were allowed to express their opinions and confront them with each other [35], a globe and plasticine balls were used to simulate cosmic phenomena [15], inquiry-based games were used [11], multimedia programmes were used [23], there was regular switching between the map and globe [36], and geographical characteristics were taken into account [2,10]. Previous research focused on establishing the effectiveness of single forms of educational interventions. This paper presents the results of a study in which most of these forms were used: conversations and discussions, building a model of a spherical Earth and using it in simulations, and supplementing the resulting experience by watching computer animations.

Studies have shown that without a proper introduction and the right sequence, the educational materials may even hinder the learning process [4]; moreover, they may promote the development of non-scientific concepts [21]. For this reason, the present study focused on analysing a structure of interventions that would maximally support children in forming the concept of a spherical Earth. Children's visuo-spatial reasoning abilities were adopted as a starting point, which may be particularly important in the formation of astronomical concepts [23]. The author invoked the concept of Nikolai N. Poddyakov [37], who explains how to support children in their transition from concrete-motor thinking, which requires performing operations on objects, to concrete-pictorial thinking allowing the use of operations in the mind. Due to the lack of an English translation of the publication, the following paragraph presents the essence of Poddyakov's explanation as it was published in Polish [37].

> *As children develop concrete-pictorial thinking, actions previously performed on real objects begin to be reproduced in the imaginary plane without the help of actual objects. A particular detachment of actions from reality takes place. It is more effective when it does not occur immediately, but goes through intermediate stages, i.e., a child reproduces these actions not on real objects, but on substitute objects, i.e., models. Initially, the model may appear as an exact copy of the object. Then, too, fundamental changes in the child's activity are already taking place. The child operates on the model of the object and, with the help of an adult, comes to an understanding of what a model is, compares the actions performed on it with the original. In other words, children realise quite quickly that their actions relate to the original, although they are performed on the model. This is a crucial moment in the formation of pictorial thinking, in which models and actions performed on them play an important role.*

Poddyakov's concept, briefly presented here, indicates that when teaching children about the shape of the Earth, one should construct a model of the planet before introducing a globe. According to Poddyakov, by operating on such a model, children will more easily assimilate the phenomena associated with the Earth model. It was recognised that for astronomical topics, the application of Poddyakov's didactic model has practical relevance within the precursor model concept, which has traditionally been used to explain physical phenomena [25].

The starting point for organising effective learning situations according to the precursor model is to have a good understanding of the children's learning process [31,33]. The way children learn and the changes that occur in the way they think are already known. Therefore, appropriate activities can be prepared. Poddyakov hints that by using a ball, we can create a three-dimensional model of the Earth and, by performing activities on it, help children move to the globe. Nowadays, using computer animations can further support this learning process. With the help of animation, we can smoothly change perspective, e.g., move from the surrounding flatness to the sphericity of the Earth. The effectiveness of such activities is described in the article.

1.3. Testing Effectiveness of the Intervention

Educational effectiveness is measured by means of pedagogical experiments in which effectiveness is measured by comparing pretest and posttest results [16,38]. Comparisons to a non-intervention control group are not used. Knowledge testing usually takes the form of an interview [17], sometimes supplemented by an analysis of children's drawings [21]. Tests are used far less frequently to assess children's knowledge [11,39]. Despite its limitations (no possibility to trigger internal models, [40]), a test economically establishes the embeddedness of a concept in the knowledge structure. An example of such a tool is the EARTH2 forced-choice test [40]. It checks whether children use the concept of the Earth's shape to explain other phenomena (e.g., movement of people on Earth).

A posttest conducted in order to assess the effectiveness is usually carried out shortly after the end of the intervention, i.e., two weeks. A certain postponement of the posttest serves to assess knowledge that is well established rather than fresh. In studies conducted with a very short postponement, children have shown to be able to still recall the scientific explanations given during the intervention [15,17]. If the postponement was longer, children gave fewer details and more often tended to return to initial explanations based on everyday experiences [20]. In studies where children's knowledge was tested after several years, it was found that students referred back to everyday experiences [38]. These findings are consistent with the shape of the learning curve and suggest that in the case of concepts that contradict everyday experiences, more frequent repetition is needed. However, there is a concern that the longer the intervention process continues, the more other factors may be affecting the final educational effect, i.e., it becomes more difficult to determine the effectiveness of the intervention as such. Under such conditions, a postponed posttest may lose relevance.

2. Materials and Methods

The aim of the study was to determine the effectiveness of an educational intervention in helping children construct the concept of the Earth's shape through the process of building a cosmological model of the Earth prior to the introduction of a globe. The main method used to achieve the study objective was a pedagogical experiment. It consisted of carrying out an educational intervention among the children and seeing how their views changed, following a series of activities.

The educational intervention was implemented based on an astronomy education programme designed by the author. The programme had been created on the basis of the model of development of basic astronomical concepts [19], precursor model concept [31], and Poddyakov's ideas on constructing a didactic model [37]. According to the developmental model, the concept of the Earth's shape forms the basis for understanding the phenomena seen in the sky (space), the location of people on Earth, the phenomenon of day and night, the phases of the Moon, and the structure of the Solar System.

The main objective of the programme was to support the children in constructing the concept of the Earth's shape and then use this as a starting point for discussing further astronomical topics. The programme was divided into five stages. The first three involved a gradual transition from observing the sky to building a model of a spherical Earth and then replacing it with a globe. The next two stages used the globe to explain more advanced cosmic phenomena. The focus below is on discussing the first three stages as the subject of the research discussed in the article.

The first stage involved a series of activities devoted to sky observation. During these activities, pupils observed the solar eclipse phenomenon. The structure of the sky was discussed with the children, and its movement was simulated with the help of computer programmes (e.g., Celestia, NASA Eyes). Attention was drawn to the regularity of celestial phenomena. The second stage focused on forming a concept of the Earth's shape by creating a spherical Earth model. For this purpose, a huge inflatable ball with the continents marked on it was placed in front of the children. A small card with a hand-drawn person, clouds, and a car was stuck to its surface. It was explained that *this is where we live* and *the person is you*. The Google Street app was displayed on a large screen, and the place where we were currently located was found. The view of the immediate surroundings was shown (Figure 1a). It was pointed out that the same place was schematically represented by the drawing attached to the ball (Figure 1b). In the app, the "camera" was lifted to show the street from above and then zoomed out to a view of the city and the continent. An image of a sphere appeared on the screen. The name of a distant location (e.g., New York) was given along with the following suggestion: *Let's see how people live there*. The animation shifted the view of the planet to show a new area. Then, it zoomed in on the city until the image was magnified to a street view. When asked by the teacher, the children again established how *people walk on the street as we do, drive cars as we do, and there are clouds above them*. The teacher showed the children a second piece of paper with a drawing of a person, clouds, and a car and asked if it was the same on this piece of paper. He stuck it on the ball roughly where New York is, i.e., on the other side of the ball. The lives of people in Australia, Japan, South Africa, Greenland, etc., were analysed in a similar way. During each visit, cards with pictures of people would be attached to the ball. When there were many pictures (Figure 1c), a generalisation was made by pointing out the difference in perspectives in relation to people, cars, and clouds. The following was said: *See, people live on all sides of the planet. Some—relative to us—move upside down*. Similarly, we noted the following: *Cars drive from all sides of the Earth and clouds move over the surface of the whole Earth*.

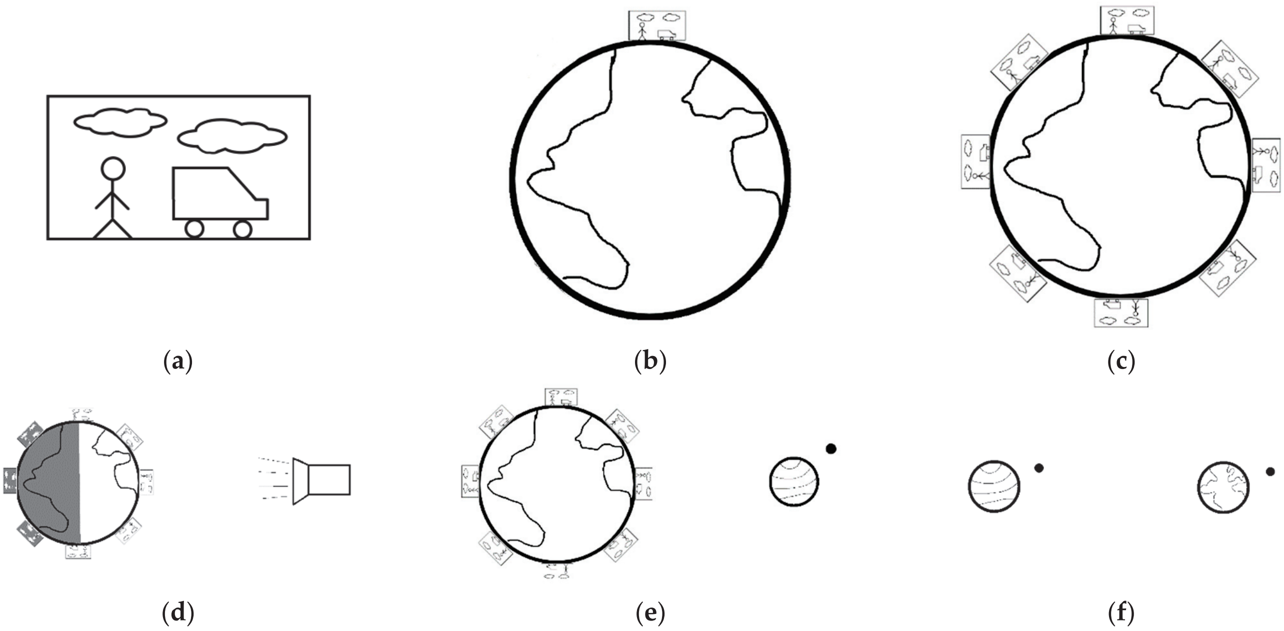

Figure 1. (**a**) Schematic drawings presented to children; (**b**) drawing attached onto a large ball to mark current location on Earth; (**c**) drawings attached to each side of the Earth. Analysis of the location of people, cars, and clouds; (**d**) simulation using a self-made model of the Earth to illustrate day-and-night phenomena; (**e**) replacing the self-made model with a ball to illustrate the actual distance between the Earth and the Moon; and (**f**) replacing the ball with a globe and drawing attention to the lack of visible elements of the Earth.

During the following class, the model of the Earth with cards stuck on was revisited to explain the phenomenon of day and night. The room was dark, and a torch was used to draw attention to the illuminated and unilluminated surface of the ball (planet), as well as pictures of people for whom it was day or night (Figure 1d). Then, the teacher ran an app demonstrating the position of the planet relative to the sun and showing its current illumination.

In the third stage, the self-made model was replaced by a globe. It was explained that with such a huge ball (Earth), the Moon would have to be several hundred metres away. In order to reduce the distance, the Earth should be reduced to the size of a small ball (Figure 1e). A small ball was then presented to the children, and it was explained that at this distance, the Moon would be the size of a ping-pong ball. The ball was then replaced with a globe of similar size, and it was explained that the globe is already so small that you cannot see all of the people, houses, and even cities on it (Figure 1f). However, *we know they are there*. Using the app, they practised finding out where they lived and marked it on the globe.

The above three stages contain a practical reference to N.N Poddyakov's concept and the concept of precursor models. A series of activities devoted to the concept of the Earth's sphericity was carried out over seven school classes. The classes took place, implemented once a week (on average) for a period of three months from October to December. The programme was carried out with a group of 47 first- and second-grade primary school students (7 and 8 years old) comprising 24 boys and 23 girls. The selection of students for the study was based on the school's designation by the foundation organising the astronomy education project. The students participating in the project had not previously engaged in astronomy education activities beyond those included in the standard curriculum.

In order to determine the effectiveness of the intervention (experimental factor), a single-group technique was adopted as the experimental method because it allows one to focus on determining the effect of an educational intervention.

The pictorial forced-choice test EARTH2, Earth Representation Test for Children (Appendix A), was chosen as a tool to evaluate the educational effectiveness of the programme. Its answers (pictures) are based on the mental models of Vosniadou and Brewer [3,27]. The assumption was that a child marking a picture would at the same time reveal its mental model. By analysing the marked pictures, it is possible to check to what extent children adhere to the spherical image of the Earth to explain problems such as the location of people, trees, and clouds; the way people move on Earth; and the phenomenon of day and night. The test had been translated into Polish and checked for the possibility that Polish children might reveal other beliefs than those included in the test [19].

The EARTH2 test was used twice during the study. The first was in October, just before the start of the intervention (pretest), and the next was in January, one month after completion of the first three stages of programme implementation (posttest), during which the children were supported in constructing an image of the spherical shape of the Earth. The EARTH2 test is a screening tool that allows one to establish pupils' competencies in a short period of time. This tool has been used to assess the effectiveness of an educational intervention among children in the past [11,39].

3. Results

Previous studies did not usually involve building cosmological models but merely used ready-made ones (e.g., a globe) or referred to objects as substitutes (a ball is the Moon). The study followed Poddiakov's concept and the concept of precursor models, which involve gradually building a model of a spherical Earth and transferring actual locations to the Earth model in stages (computer programmes were used for this purpose). The effectiveness of such an organisation of the study was demonstrated by the difference between the pretest and posttest.

A pretest to assess students' knowledge prior to the intervention was used to determine whether students already had a well-structuralised idea of the shape of the Earth prior to the activity. The detailed results of the pretest are presented in Appendix B (Table A1). Before the results are presented, it should be noted that a spherical image of the Earth, in addition to scientific answers, was also included in some answers referring to synthetic models (e.g., people only live in the northern hemisphere); therefore, in the presentation of the results, we make a distinction and separately report about the answers referring to the scientific model and those that simply indicate illustrations (models) that represent a spherical Earth. The study found that, prior to the intervention, one in three students tested (30%, 14 out of 47) consistently adhered to the Earth as a sphere when answering all of the questions without necessarily indicating the scientific answer. In contrast, one in five (19%, 9 students) indicated the correct answers to all questions in the test.

Apart from a few photographs (Figure 2a,b), the activities were not recorded, but after each session, a brief note was written about the children's statements and behaviour.

(**a**)

(**b**)

Figure 2. (**a**) Lesson on the way people live in different parts of the world and attaching pictures to each side of the ball-Earth; (**b**) the self-made model is replaced by a globe.

Fears around the dangers of asteroids and comets passing close to Earth were evident in the children's questions and behaviour. During the class, each of the dangers was explained using rational evidence, e.g., examples of space projects that have so far been developed to defend against space rocks (e.g., the DART programme).

After completing the series of classes (three stages of the educational programme), the test was repeated. Detailed results of the posttest are included in Table A2 in Appendix B. After the astronomy classes, almost twice as many students as during the pretest (43%, 20 out of 47 students) consistently adhered to the image of the Earth as a sphere and indicated the scientific answers (38%, 18 students). These results confirm the effectiveness of the educational intervention undertaken.

The comparison of pretest and posttest results also took into account the distinction between initial, synthetic, and scientific models (following the classification of Vosniadou and Brewer [3]). All answers (pictures) that represent the Earth as a flat disk were classified as initial models, and those that represented the Earth as a sphere were classified as scientific models. All answers in between were classified as synthetic models (cf. Appendix A).

No change in the children's answers to the test (regarding their correctness) was observed in the case of five children. Further, five children (11%) pointed to the scientific model in all questions in the pretest and posttest. This means that by the time the educational activities started, the pupils already knew the correct answer to the questions in the test. For the remaining 37 children, 142 changes were noted. They were divided according to the direction in which the changes occurred:

- Most changes were progressive (49%, 69 cases). They involved moving from an initial to a synthetic model (9 students). As a consequence, students no longer marked a disk-shaped Earth, whereas moving from a synthetic model to a scientific one (36 students) and from an initial model to a scientific one (24 students) entailed adopting information about the spherical shape of the Earth but also the location of objects or phenomena. All progressive changes consisted of the gradual abandonment of answers derived from everyday observation and the adoption of scientific information;

- Regression was noted in 30 cases (21%). Reverting to previous beliefs was evident in three types of change: (a) regressive changes involving abandoning the scientific model and indicating the synthetic model (21 students), (b) regressive changes involving abandoning synthetic models and indicating initial models (3 students), (b) regressive changes involving abandoning the scientific model selected in the pretest and indicating the initial model in the posttest (6 students). Such changes consisted of a return to a strong impression treating the Earth as a disk as the concept of the Earth's shape is still forming in the conceptual structure;
- No change or a change within the same non-scientific model (from initial to another initial and from synthetic to another synthetic) was present in one in every three cases (30%). This shows that the formation of the Earth's shape concept is still ongoing.

The above results indicate that the procedure used during the intervention was successful. The transition from the flat Earth seen in everyday life to the view of a spherical Earth and building a model of it involved showing two different perspectives. Thanks to the computer animations used, it was possible to show the transition between the two. In turn, the gradual reduction in the self-made model of the Earth, ending with its replacement by a globe, was aimed at supporting the process of abstraction. The children learned that the information that was encoded during the activities on the Earth model (people, clouds, and cars depicted in the pictures) is located on the Earth but is too small to be represented. This form of placing information on the surface of the Earth model (which is close to coding it) was an important part of the transition from flatness to sphericity of the Earth.

During the intervention, no detailed analysis of the children's behaviour was carried out, but a brief note of the activities was written after each meeting. The children's statements and behaviour were recorded in this form. The children brought books about the cosmos and posed difficult questions written down in advance on cards. These questions went far beyond the subject matter of the class and came from media messages. Most often, they concerned space objects flying close to Earth, but there were also questions on preparations for the landing of man on Mars, space missions, and black holes. The particularly challenging questions the children presented were as follows:

- *Is it true that the James Webb telescope has discovered constellations older than the Big Bang, stars formed by the Sagittarius A and B black holes, galaxies that formed some 371,000 years after the Big Bang?*
- *Is there an infinite black hole? One that has infinite mass?*

Asking such questions suggests that first-grade students are curious about topics that are much more distant from what has been planned for them in the curriculum. It was observed that the increased interest in space topics was also related to greater attention to media reports. Many of the questions were about threats from space. During the class, the post-activities undertaken by adults to avoid dangers (such as the DART programme) were explained. All of this indicates that the topics of children's interest go far beyond the curriculum.

4. Conclusions and Discussion

The study has shown that half of all observed changes between the pretest and posttest were progressive, demonstrating the effectiveness of the assumption made regarding the construction of Earth models prior to the introduction of a globe. One in three changes involved the selection of a different synthetic model. In contrast, one in five changes were regressive in nature and involved selecting those images that were closer to everyday experiences. Results of the study confirm the effectiveness of structured educational interventions and demonstrate that appropriately organised educational activities can be effective in supporting children in forming the concept of a spherical Earth [10–12,23]. The findings indicate that constructing a concept is a process related to incorporation into the knowledge structure. All of the changes revealed in the study (progression and regression) are evidence of the child's mind working to align the new concept with its mental structure [31].

Multiple forms of impact were used in the intervention. Coding the figures using pictures on the ball-Earth was an activity that helped the children identify with their place on the ball, whereas sticking more cards on the ball enabled the children to see that both people and vehicles are all around the Earth and do not fall off the Earth. Clouds, on the other hand, form the layer of atmosphere that surrounds the Earth. These issues are important for building further concepts, not only astronomical ones. With a ball as a model of the Earth, a simulation of the day-and-night phenomenon was carried out to better explain this complex phenomenon. The ball model was then replaced by a globe, which was used as a model of the Earth in subsequent activities. Computer animations were also used during the intervention as a form of learning support. Zooming in and out of the image of the Earth on the screen helped to explain what a change in perspective was. Thus, the effectiveness of employing conversations with children [33,34], didactic models, and simulations [11,15], as well as programmes that allow one to switch between the map (visible on the screen) and the globe [2,10,23,35], was confirmed. This list of effective influences can be supplemented by a procedure of constructing a spherical Earth model before introducing a globe as a ready-made model containing a lot of codified data (e.g., inclination of the Earth's axis and distances between cities).

The constructivist approach, which is the pillar of the study described here, is based on the assumption that, during organised activities, children can take the elements they need to build their knowledge of the world. Each of the children, operating at a different stage in the formation of the spherical Earth concept, drew those elements from the activities that were important to them. The fact that not all children have yet grasped the concept and that some of them revealed a regression in the posttest confirms that the integration of the concept of the Earth's shape into the mental structure is a long-term process that requires restructuring (accommodation). The difficulty in mastering this concept confirms previous research findings [18,21].

Research also confirms that changes in the conceptual structure related to the shape of the Earth do not happen suddenly [18]. Rather, they are a gradual process that requires appropriate educational support. When support is lacking, concept development stalls or even regresses, and children resort to the strong image of a flat Earth again [20,38]. Studies conducted among 9- and 10-year-old children who were not taught the shape of the Earth show that half of the respondents gave up the spherical Earth explanation when asked to explain cosmic phenomena [19]. The study also confirms that the development of key concepts (including the shape of the Earth) needs to be addressed quickly to avoid the development of coherent non-scientific models [21].

The intervention triggers children's interest in the topic of space [12]. This, in turn, generates the need to ask questions and sometimes seek answers on their own [11]. Children started to pay more attention to media reports, which, in turn, gave rise to further questions. Their content significantly exceeded the scope of curricular contents intended for the first grade. This, therefore, confirms the need to extend the scope of astronomy education [13]. However, the extension should include issues currently appearing in media messages—space discoveries and space technology. Such an extension of astronomy classes would enliven them and bring them up to date with what is often emphasised in astronomy education [16].

Conversations with the children revealed their fears about space. It seems that for some children, these classes were the first opportunity to think about the existence of dangers from space. During the activities, fears were discussed at length, and actions taken by adults to avoid dangers were explained. This confirms previous research observations [13] and points to the need for a deeper understanding of this area as well as for the development of educational activities that should include alleviating children's fears.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institute of Human Development Support and Education, The Maria Grzegorzewska University (date of approval V/2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

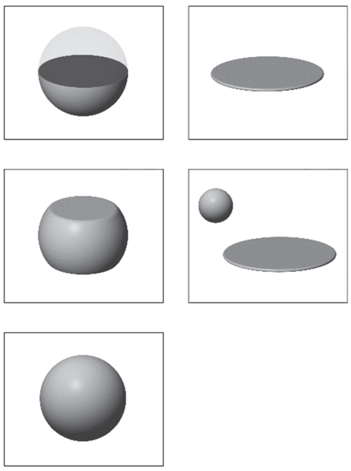
Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The author declares no conflict of interest.

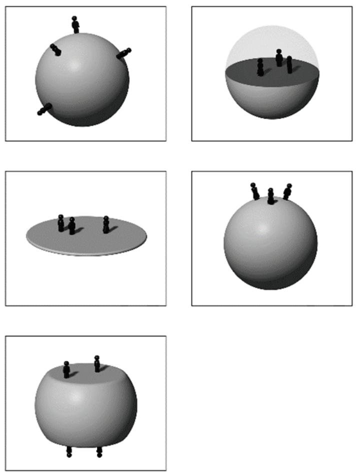
Appendix A

Earth Representation Test for children, version 2 (EARTH2) [40]. In presenting the following questions, the trial question "mark the cat" was omitted; this question was available in the original and online versions.

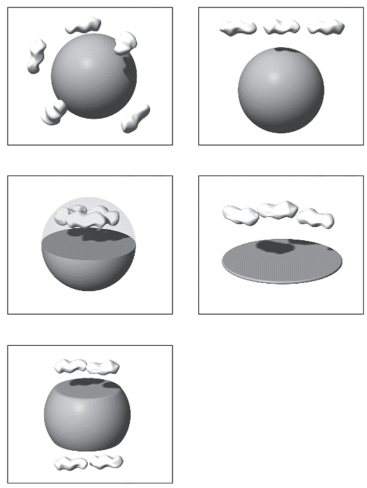
1. What does the earth look like?



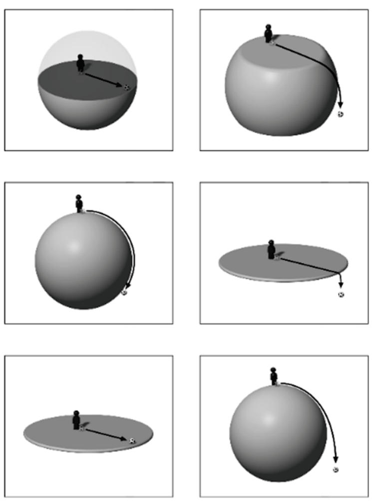
2. Which picture shows best where the people live on the earth?



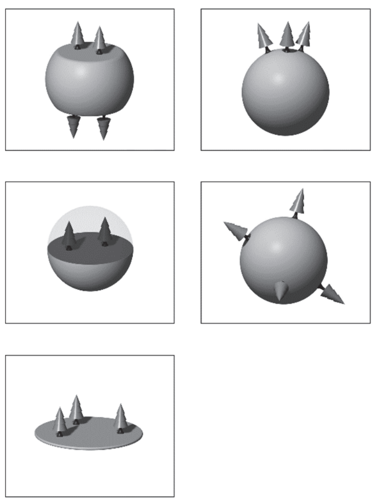
3. Which picture shows best where the clouds are?



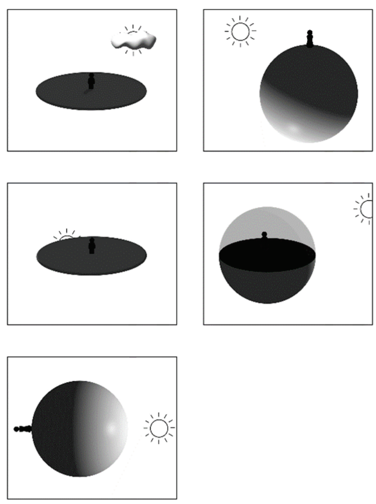
4. Which picture shows best what happens when a giant kicks a ball real hard?



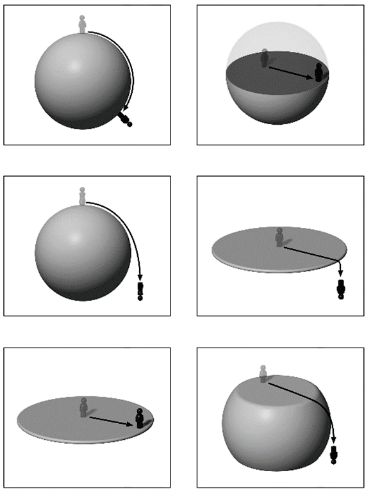
5. Which picture shows best where the trees are on the earth?



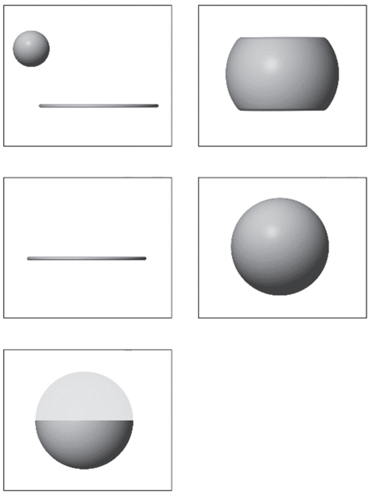
6. Where is the sun at night?



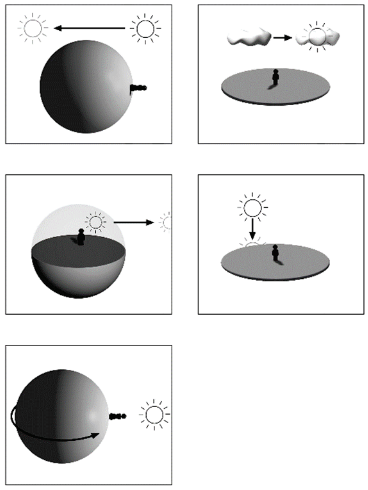
7. What happens when you walk along a straight line for a very long time?



8. Which picture resembles the earth best?



9. Which picture shows best how night falls?



Appendix B

Table A1. Distribution of responses in the test before the educational intervention (pretest).

Question	Initial Model		Synthetic Model				Scientific Model
	Flat Earth		Hollow	Dual	Flattened	No Gravity	Scientific
1. What does the earth look like?	0		0	1 (2.1%)	3 (6.4%)	-	43 (91.5%)
2. Which picture shows best where the people live on the earth?	4 (8.5%)		4 (8.5%)	-	0	4 (8.5%)	35 (74.5%)
3. Which picture shows best where the clouds are?	7 (14.9%)		3 (6.4%)	-	0	5 (10.6%)	32 (68.1%)
4. Which picture shows best what happens when a giant kicks a ball real hard?	1 (2.1%) Falls off the Earth	6 (12.8%) Does not fall off the Earth	2 (4.3%)	-	1 (2.1%)	13 (27.7%)	24 (51.1%)
5. Which picture shows best where the trees are on the earth?	3 (6.4%)		4 (8.5%)	-	0	7 (14.9%)	33 (70.2%)
6. Where is the sun at night?	1 (2.1%) Cloud	11 (23.4%) Sundown	1 (2.1%)	-	-	3 (6.4%)	31 (66.0%)
7. What happens when you walk along a straight line for a very long time?	2 (4.3%) Does not fall off the Earth	6 (12.8%) Falls off the Earth	1 (2.1%)	-	0	2 (4.3%)	36 (76.6%)
8. Which picture resembles the earth best?	0		0	0	0	-	47 (100%)
9. Which picture shows best how night falls?	1 (2.1%) Cloud	21 (44.7%) Sundown	0	-	-	8	17 (36.2%)

Table A2. Distribution of responses in the posttest of the Earth shape education intervention series (posttest).

Question	Initial Model	Synthetic Model				Scientific Model
	Flat Earth	Hollow	Dual	Flattened	No Gravity	Scientific
1. What does the earth look like?	1 (2.1%)	0	3 (6.4%)	3 (6.4%)	-	40 (85.1%)
2. Which picture shows best where the people live on the earth?	3 (6.4%)	2 (4.3%)	-	0	1 (2.1%)	41 (87.2%)

Table A2. *Cont.*

Question	Initial Model		Synthetic Model				Scientific Model
	Flat Earth		Hollow	Dual	Flattened	No Gravity	Scientific
3. Which picture shows best where the clouds are?	4 (8.5%)		2 (4.3%)	-	0	3 (6.4%)	38 (80.9%)
4. Which picture shows best what happens when a giant kicks a ball real hard?	1 (2.1%) Falls off the Earth	4 (8.5%) Does not fall off the Earth	5 (10.6%)	-	0	0	37 (78.7%)
5. Which picture shows best where the trees are on the earth?	4 (8.5%)		1 (2.1%)	-	0	3 (6.4%)	39 (83.0%)
6. Where is the sun at night?	1 (2.1%) Cloud	5 (10.6%) Sundown	1 (2.1%)	-	-	2	38 (80.9%)
7. What happens when you walk along a straight line for a very long time?	0 Falls off the Earth	4 Does not fall off the Earth	3 (6.4%)	-	0	1 (2.1%)	39 (83.0%)
8. Which picture resembles the earth best?	0		0	1 (2.1%)	0	-	46 (97.9%)
9. Which picture shows best how night falls?	2 (4.3%) Cloud	9 (19.1%) Sundown	2 (4.3%)	-	-	12 (25.5%)	22 (46.8%)

References

1. Saçkes, M.; Smith, M.M.; Trundle, K.C. US and Turkish Preschoolers' Observational Knowledge of Astronomy. *Int. J. Sci. Educ.* **2016**, *38*, 116–129. [CrossRef]
2. Kampeza, M.; Ravanis, K. Transforming the Representations of Preschool-Age Children Regarding Geophysical Entities and Physical Geography. *Rev. Sci. Math. ICT Educ.* **2009**, *3*, 141–158.
3. Vosniadou, S.; Brewer, W.F. Mental Models of the Earth: A Study of Conceptual Change in Childhood. *Cogn. Psychol.* **1992**, *24*, 535–585. [CrossRef]
4. Mali, G.B.; Howe, A. Development of Earth and Gravity Concepts among Nepali Children. *Sci. Educ.* **1979**, *63*, 685–691. [CrossRef]
5. Gallegos-Cázares, L.; Flores-Camacho, F.; Calderón-Canales, E. Elementary School Children's Explanations of Day and Night. *Sci. Educ.* **2022**, *31*, 35–54. [CrossRef]
6. Frède, V. Comprehension of the Night and Day Cycle among French and Cameroonian Children Aged 7–8 Years. *Cult. Stud. Sci. Educ.* **2019**, *14*, 587–615. [CrossRef]
7. Bar, V.; Brosh, Y.; Sneider, C. Weight, Mass, and Gravity: Threshold Concepts in Learning Science. *Sci. Educ.* **2015**, *24*, 22–34.
8. Agan, L.; Sneider, C. Learning about the Earth's Shape and Gravity: A Guide for Teachers and Curriculum Developers. *Astron. Educ. Rev.* **2003**, *2*, 90–117. [CrossRef]
9. Blown, E.J.; Bryce, T.G.K. The Enduring Effects of Early-Learned Ideas and Local Folklore on Children's Astronomy Knowledge. *Res. Sci. Educ.* **2020**, *50*, 1833–1884. [CrossRef]
10. Baldy, E. Children's Representation of the Earth at the End of Elementary School: The Role of Spherical and Geographical Information Carried by the Globe. *Rev. Sci. Math. ICT Educ.* **2023**, *17*, 5–25. [CrossRef]
11. Özgül, S.G. Integration of Inquiry and Play: Young Children's Conceptual Change in Astronomy. *JIBA* **2021**, *11*, 1–15.
12. Yalçınkaya-Önder, E.; Timur, B.; Özeş, B.; Timur, S. Astronomy Education for Preschool Children: Exploring the Sky. *Int. Electron. J. Elem. Educ.* **2020**, *12*, 383–389. [CrossRef]
13. Raviv, A.; Dadon, M. Teaching Astronomy in Kindergarten: Children's Perceptions and Projects. *Athens J. Educ.* **2020**, *7*, 305–327. [CrossRef]
14. Kampeza, M.; Ravanis, K. Children's Understanding of the Earth's Shape: An Instructional Approach in Early Education. *Skholê* **2012**, *17*, 115–120.
15. Kallery, M. Astronomical Concepts and Events Awareness for Young Children. *Int. J. Sci. Educ.* **2011**, *33*, 341–369. [CrossRef]
16. Lelliott, A.; Rollnick, M. Big Ideas: A Review of Astronomy Education Research 1974–2008. *Int. J. Sci. Educ.* **2010**, *32*, 1771–1799. [CrossRef]
17. Valanides, N.; Gritsi, F.; Kampeza, M.; Ravanis, K. Changer Les Conceptions d'Enfants d'Â Ge Préscolaire Sur Le Phénoméne Du Cercle 'Jour–Nuit'. *Int. J. Early Years Educ.* **2000**, *8*, 27–39. [CrossRef]
18. Vosniadou, S. Initial and Scientific Understandings and the Problem of Conceptual Change. In *Converging Perspectives on Conceptual Change: Mapping an Emerging Paradigm in the Learning Sciences*; Amin, T.G., Levini, O., Eds.; Routledge: New York, NY, USA, 2017; pp. 17–25, ISBN 978-1-138-20540-6.
19. Jelinek, J.A. Children's Astronomy. Development of the Shape of the Earth Concept in Polish Children between 5 and 10 Years of Age. *Educ. Sci.* **2021**, *11*, 75. [CrossRef]

20. Hannust, T.; Kikas, E. Changes in Children's Answers to Open Questions about the Earth and Gravity. *Child. Dev. Res.* **2012**, *22*, 89–104. [CrossRef]
21. Hannust, T.; Kikas, E. Children's Knowledge of Astronomy and Its Change in the Course of Learning. *Early Child. Res. Q.* **2007**, *22*, 89–104. [CrossRef]
22. Vosniadou, S. Capturing and Modeling the Process of Conceptual Change. *Learn. Instr.* **1994**, *4*, 45–69. [CrossRef]
23. Shaikh, R.; Padalkar, S.; Stump, G.; Sutar, P.; Kumar, A. Learning Basic Astronomy through an Embodied and Interactive Approach. *Int. Conf. Rev. Res. Sci. Technol. Math. Educ.* **2020**, *3*, 463–474.
24. Wadsworth, B.J. *Piaget's Theory of Cognitive and Affective Development: Foundations of Constructivism, 5th ed*; Longman Publishing: White Plains, NY, USA, 1996; p. xi, 195. ISBN 978-0-8013-0773-7.
25. Ravanis, K. The Physical Sciences in Early Childhood Education: Theoretical Frameworks, Strategies and Activities. *J. Phys. Conf. Ser.* **2021**, *1796*, 12092. [CrossRef]
26. Vosniadou, S.; Skopeliti, I.; Ikospentaki, K. Modes of Knowing and Ways of Reasoning in Elementary Astronomy. *Cogn. Dev.* **2004**, *19*, 203–222. [CrossRef]
27. Vosniadou, S.; Brewer, W.F. Mental Models of the Day/Night Cycle. *Cogn. Sci.* **1994**, *18*, 123–183. [CrossRef]
28. Nussbaum, J.; Novak, J. An Assessment of Children's Concepts of the Earth Utilizing Structured Interviews. *Sci. Educ.* **1976**, *60*, 535–550. [CrossRef]
29. Jelinek, J.A. Children's Astronomy. Shape of the Earth, Location of People on Earth and the Day/Night Cycle According to Polish Children between 5 and 8 Years of Age. *Rev. Sci. Math. ICT Educ.* 2020, *Forthcoming papers*.
30. Diakidoy, I.-A.; Vosniadou, S.; Hawks, J. Conceptual Change in Astronomy: Models of the Earth and of the Day/Night Cycle in American-Indian Children. *Eur. J. Psychol. Educ.* **1997**, *12*, 159–184. [CrossRef]
31. Delserieys, A.; Jégou, C.; Boilevin, J.-M.; Ravanis, K. Precursor Model and Preschool Science Learning about Shadows Formation. *Res. Sci. Technol. Educ.* **2018**, *36*, 147–164. [CrossRef]
32. Weil-Barais, A. Constructivist Approaches and the Teaching of Science. *Prospects* **2001**, *31*, 187–196. [CrossRef]
33. Lemeignan, G.; Weil-Barais, A. A Developmental Approach to Cognitive Change in Mechanics. *Int. J. Sci. Educ.* **1994**, *16*, 99–120. [CrossRef]
34. Chi, M.T.; VanLehn, K.A. The Content of Physics Self-Explanations. *J. Learn. Sci.* **1991**, *1*, 69–105. [CrossRef]
35. Vosniadou, S.; Ioannides, C.; Dimitrakopoulou, A.; Papademetriou, E. Designing Learning Environments to Promote Conceptual Change in Science. *Learn. Instr.* **2001**, *11*, 381–419. [CrossRef]
36. Prain, V.; Tytler, R. Theorising Learning in Science Through Integrating Multimodal Representations. *Res. Sci. Educ.* **2021**, *52*, 805–817. [CrossRef]
37. Podd'yakov, N. *Preschooler's Thinking*; Pedagogika: Moscow, Russia, 1977.
38. Kikas, E. The Impact of Teaching on Students' Definitions and Explanations of Astronomical Phenomena. *Learn. Instr.* **1998**, *8*, 439–454. [CrossRef]
39. Vaiopoulou, J.; Papageorgiou, G. Primary Students' Conceptions of the Earth: Re-Examining a Fundamental Research Hypothesis on Mental Models. *Ppej* **2018**, *6*, 23–34. [CrossRef]
40. Straatemeier, M.; van der Maas, H.L.J.; Jansen, B.R.J. Children's Knowledge of the Earth: A New Methodological and Statistical Approach. *J. Exp. Child. Psychol.* **2008**, *100*, 276–296. [CrossRef]

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Article

Condensation and Precipitation of Water Vapor: The Emergence of a Precursor Model through the Engineering Design Process

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Abstract: Early Childhood Science Education, within a wide range of research topics, studies mental representations of children aged 3–8 years about natural phenomena. Recently, there has been a strong scientific interest in the way children construct precursor mental models. The current study attempts to address children's mental representations of clouds, as well as condensation and the precipitation of water vapour. To fulfill this goal, a qualitative study was implemented involving 19 preschool children. Specifically, the survey included pre-tests and post-tests for recording children's mental representations, as well as a structured teaching process. The main activities of this teaching process followed the four stages of the Engineering Design Process and a STEAM approach, adapted both to children's cognitive needs and the conditions of a real classroom. The results showed that most children of this age (mean age: 5.05 years) were able to approach the concepts of condensation and precipitation, as well as the process of cloud creation. It seems, therefore, that it is possible for young children's initial mental representations to be transformed into representations compatible with school knowledge. Finally, the data and the results of the research lead to the conclusion that children of this age are capable of constructing a precursor model about clouds and the phenomena of condensation and precipitation.

Keywords: mental representations; precursor model; condensation; precipitation; Engineering Design Process

1. Introduction

Early Childhood Science Education sets itself in a wide spectrum that encompasses distinct study fields such as Early Childhood Education, Educational Psychology, and Science Education. This new field, both from a theoretical and a research point of view, covers a number of issues that are related to the development of scientific educational environments and the training of teachers, as well as the learning and teaching of natural sciences to students aged 3–8 years old. Within this context, a distinct direction of research is the study of young children's mental representations of scientific concepts and phenomena, the obstacles they create in the conceptualization of the scientific phenomena, and strategies to deal with these obstacles through developmentally appropriate activities [1–3].

Within a special perspective, modern research in this study area deals not only with the transformation and evolution of some mental representations but also with the formation of precursor models in children's thinking. These are stable entities that have two main characteristics: (a) They interpose themselves, as dynamic forms of thinking, between naive mental representations and scientific knowledge taught in schools and (b) They hold specific characteristics of scientific models, such as the use of appropriate variables that allow satisfactory descriptions and the formulation of predictions for the evolution of physical phenomena [4].

During the last few decades, a new research field was shaped around STEM education that describes an interdisciplinary approach to Science, Technology, Engineering, and Mathematics [5]. Lately, Arts were added to the acronym, forming the term STEAM, to enhance creativity [6–8]. Regarding early childhood settings, STEAM could also be combined with non-STEAM areas such as Literature, History, and Storytelling. In addition, everyday life situations and problems can be used and solved through the Engineering Design Process, a four-stage problem-solving process that introduces and facilitates STEAM activities in Early Childhood Education [9].

In the current research, an attempt was made to study the possibility of constructing a precursor model for the condensation and precipitation of water vapor in the thinking of approximately 5-year-old children through the creation of an educational environment based on the Engineering Design Process.

2. Theoretical Background and Literature Review

2.1. Literature Review

Early Childhood Science Education covers a wide spectrum that extends from the study of children's ideas about natural phenomena to the design and implementation of proper teaching interventions. It addresses a variety of natural science concepts and phenomena, such as mechanical phenomena [10–12], floating and sinking [13–15], thermal phenomena [16–20], light and shadows [21–24], and elementary astronomy [25–27]. A literature review that focused mainly on water state changes and the water cycle in nature revealed the positive experience that young children harbor regarding ice melting and water evaporation, as well as other related phenomena [28].

Students need to establish connections between scientific notions and their everyday life experiences and be able to utilize this new knowledge in problem-solving situations [29–31]. It seems that young children often face difficulties in learning and conceptualizing notions about water state changes. However, as research findings reveal, preschool students often have interesting experiences with thermal phenomena that enable them to approach scientific knowledge through appropriate teaching methods [1–3].

Although young children can understand phenomena such as boiling [32], most of them could face difficulties with other notions such as evaporation [33]. Tytler [34] studied the mental representations of young children, aged 6 to 7 years old, regarding evaporation and condensation, while Cruz-Guzman et al. [35] examined 2- to 4-year-old children's mental representations about the change of matter in daily material.

In their research, [36,37] revealed that young children were capable of constructing a precursor model that could support their scientific thinking regarding water state change phenomena. However, severe difficulties were recorded in the conceptualization of the condensation phenomenon. Bar's [33] research showed that 5- to 7-year-old children hold the view that God is exclusively responsible for rain without mentioning any connection with clouds, while older 6- to 9-year-old children could justify the creation of clouds through the existence of steam. Ahi [38] stated that children were able to connect rain with clouds and tended to recognize both of them as important elements of the water cycle. However, he pointed out that children often encountered difficulties with notions such as evaporation and condensation. In Savva's research [39], children also tensed to describe clouds as the source of the rain. Quite interestingly, as a literature review revealed, many 7- to 10-year-old children likened clouds to sponges with holes that let the rain fall [33,40].

Jelinek [41] used a narrative approach to examine to which extent children would be able to detect incorrect information regarding evaporation. Although only a few were able to detect errors in the story, half of the children connected cloud formation with evaporation. Malleus et al. [42] also investigated children's ideas about clouds and rainfall. They stated that while young children mainly focused on the visible aspects of clouds (e.g., made of cotton), some of them were capable of giving synthetic responses that were close to scientific thinking, recognizing that clouds were made of water vapor. Savva [39] also examined the concept of rainfall with children and found that older children could associate clouds with rainfall.

Another item of research revealed that, despite the difficulties that children may have with complex entities such as clouds, they can often offer descriptions and recognize both the characteristics of clouds and their nature [43]. In conclusion, it seems that only those 4- to 7-year-old children who either completely or partially associate water vapor with clouds and rain can conceptualize rain and cloud formation phenomena as key components of the water cycle in nature [43–45].

Based on analysis of the relevant literature, as well as school-level science knowledge about the water cycle in nature, the key structural features of a precursor model for the water cycle in nature for children aged about 5 years are the following:

(a) Firstly, the transition from the liquid to the water vapor state is solely limited to notable and well-observable 'water reservoirs' such as the sea or lakes and rivers. At the core of this choice lies the capability of utilizing the real-life experiences of young children, which can act as the starting point for teaching interventions.
(b) As a transition process, the creation of water vapor in boiling states is primarily chosen, since the phenomenon is intense and allows the centralization of the children's thinking. Although, in nature, the main process of water vapor production is evaporation without boiling, we chose boiling as it coexists with evaporation. In addition, part of the teaching process related to scratch applications on the sea, an issue which is based on the evaporation of water.
(c) The transition of water vapor to the liquid state is attributed to condensation due to cooling by air.
(d) The cycle of related phenomena is completed by precipitation and rain, which is attributed to the concentration of water droplets returning back to their original reservoirs on the Earth's surface.

All these phenomena facilitate the gradual evolution of students' thinking into higher-level models as (a) water reservoirs can incorporate the moisture of solid soil, (b) the transition from the liquid to gaseous state can be dominated by evaporation, (c) precipitation and rainfall are more complex mechanisms, and (d) the return of rain to Earth involves run-off, infiltration, and percolation.

2.2. Research Questions

In the current research, we dealt with the phenomenon of condensation and the precipitation of water vapor. In particular, our goal was to study the transition of water from the gaseous state to the liquid state, from the perspective of transforming children's mental representations from pre- to post-test while establishing a precursor model in their minds. Key elements of such a model are, on the one hand, the recognition of the physical processes of condensation of water vapor in familiar phenomena and, on the other hand, the linking of condensation with precipitation so that the thermal character of this process is consistently recognized. In this context, three research questions were formulated to investigate the potential change in children's reasoning between pre- and post-test.

The first research question examined children's mental representations of cloud creation.

The second research question examined the way children approach the cycle of condensation and the precipitation of water vapor.

The third research question studied children's mental representations of condensation of water vapor in everyday life situations.

3. Materials and Methods

3.1. Participants

The participants of this study consisted of 19 children (9 boys and 10 girls, mean age 5.05 years) who voluntarily participated in this research. They were chosen on a convenient basis as all of them attended a kindergarten class in a school in Piraeus, Greece. The research was conducted with the written consent of the children's parents and the permission of the ethics committee of the Department of Educational Sciences and Early Childhood Education of the University of Patras. While no activities on 'condensation of water vapor' had been carried out within the classroom, all of the children were familiarized with the phenomenon of boiling and the vaporization of water.

3.2. The Research Process

The research design consisted of a pre-test, four (4) main stages that followed the Engineering Design Process (EDP) for Early Childhood Education [9], and a post-test (Figure 1). The main activities that followed the 4 stages of the EDP were: (1) Problem, (2) Inquiry, (3) Designing and Testing, and (4) Conclusions and Presentation. The pre-tests were conducted a week before the main activities while the post-tests were conducted a week after the completion of the main activities.

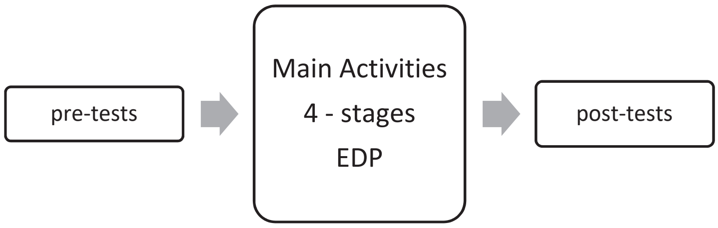

Figure 1. Research Process.

The entire research process was carried out by a researcher with extensive experience as an early childhood teacher.

3.2.1. The Pre-Test

The pre-test was conducted with semi-structured interviews, which were composed of 6 basic tasks by which children's mental representations were recorded. The discussion with the children initiated with an introductory question asking them whether and where they had ever seen clouds. The fact that all children were able to talk about this experience led to the start of the interview. The key questions of every basic task of the interview were as follows. Research question 1: Task (1) What is a cloud? Task (2) How is it created? Research question 2: Task (3) Do you know what condensation is? Have you ever heard the word precipitation? Research question 3: Task (4) If there is a pot of boiling water in the kitchen, what would happen on the kitchen cabinets? What would happen on the kitchen windows? Task (5) What if cold air suddenly blows over the pot? Task (6) Have you ever seen a factory? Have you noticed the chimneys? What comes out of there?

The discussions with the children were recorded and analysis of the data was based on the corresponding transcripts.

3.2.2. The 4 Stages of Activities According to the Engineering Design Process (EDP)

The activities were implemented in real teaching conditions and were developed in 4 stages according to the EDP [9]. The EDP is a problem-solving process that follows specific steps and constraints in order to solve problems or create prototypes. The EDP was utilized in this paper in two ways. Firstly, to design the teaching intervention and secondly by children in order to solve the problem presented to them through its 4 specific steps. Through its four steps, the EDP offers the possibility to design individual activities or projects focused on solving a specific problem; with the appropriate visualization, children can be gradually introduced to its steps in order to follow a specific process to achieve their goal [9].

In the current study, the children were asked to identify the problem Paul faces in order to interpret and analyze the phenomena he observes. Thus, children first identified the elements of the story (Problem), then expressed their experiences and ideas about the elements they identified (Inquiry), designed ways in which they could make a cloud, and observed and participated in the implementation of the experiments (Designing and Testing). Finally, due to the nature of the topic, the children created a poster to 'solve' the problem that Paul faced within the original story. In particular, they attempted to interpret the phenomenon they investigated accurately and in a way that was compatible with school knowledge, as well as communicate it to others. Finally, they focused on how, when, and why the cloud forms, even in situations other than at the factory.

Particularly, in the first stage of the EDP (Problem), the researcher narrated a story about a child named Paul. The scenario of the story was as follows: 'Paul lives in a town, near a factory, in which very large cauldrons of boiling water started to heat up. Suddenly, a white smoke, steam, began to rise from the tall and large chimneys. Large clouds began to form over the factory, which grew larger and larger'. Upon completion of the story, the children were asked to identify and define what these clouds were and how they were created. The choice of the analogy of factory chimneys was made in order to introduce the concept of steam to children through an analogy that is well-known in their everyday life experiences, as numerous factories exist in the area where these children are raised. In particular, during the implementation of the pre-tests, it appeared that some children had some experience with factories, even reporting on their own that 'white clouds' or steam and white smoke formed over the chimneys. In contrast, other children reported fire or grey smoke (when something burns) from factories or from ships in the harbor. Therefore, drawing on the distinction the children made on their own, the story of Paul, who introduces the concepts of a heat source, water, steam, and clouds, was created.

In the second stage of the EDP (Inquiry), the children were encouraged to express their ideas about the creation of clouds and the material they were made of. In addition, they were prompted to point out the role of the boiling water in the whole process, as well as to refer to everyday experiences related to the phenomenon of condensation (e.g., factories, ships, and cooking). Finally, they were encouraged to suggest possible ways of finding out what was really happening. Here, the researcher had the role of moderating the plenary discussion and recording their views on an interactive whiteboard.

In the third stage of the EDP (Designing and Testing), the children were initially asked to individually design and justify their responses regarding the possible ways of cloud creation. Subsequently, an interactive virtual simulation experiment was implemented on the classroom's interactive whiteboard. This simulation experiment was designed in a Scratch programming environment by the research team and employed with the children (Figure 2).

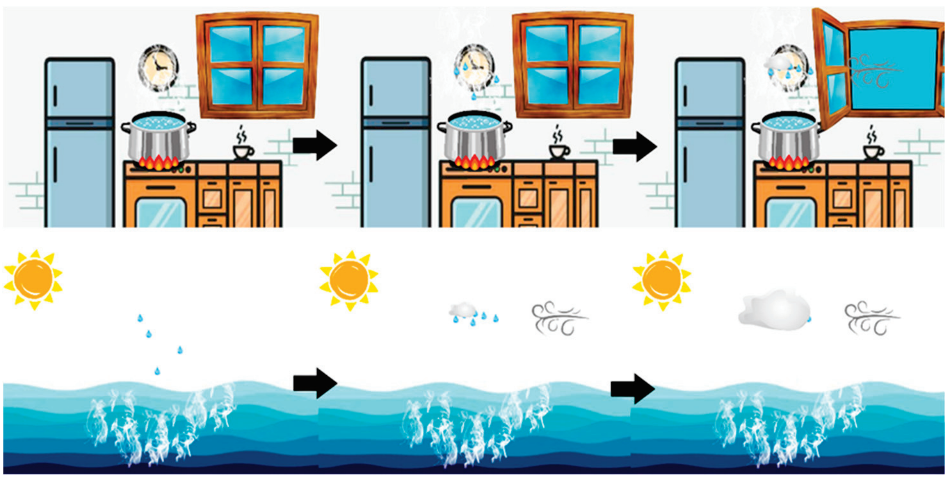

Figure 2. Interactive Virtual Experiment Simulation.

As soon as a child placed a pot of water in the kitchen, the water would start to boil, and steam and small droplets would rise upwards. Then, the kitchen window would suddenly open, and a cold wind would blow. As a result, a cloud was created in the room. Subsequently, cloud creation was transferred to the context of the sea, where the sun would heat its surface and droplets would rise up to the sky. These droplets met cold air masses which led to the creation of clouds. At this phase, the teacher introduced the terms 'condensation' and 'precipitation'.

At the end of this activity, two experiments were carried out in the physical space of the classroom: (a) boiling water in a pot next to a side window and (b) boiling water in a pot covered with a transparent lid. The children were asked to carefully observe and predict what would happen in each experiment.

Finally, the children divided into groups had the opportunity to play the music-motor game 'steam–cloud'. According to the game, the children were able to move freely in the classroom as steam, while they had to approach each other and move in a cloud-group as soon as the 'cold wind' started blowing.

In the final stage of the EDP ('Conclusions and Presentation'), children were invited to present their findings and conclusions to another class of the school as well as their parents. The teacher provided children with a number of different materials (cardboard, brushes, and paints) and, as a group, the teacher along with the children decided how to carry out their presentation. Here, the children were asked to emphasize how they rediscovered what clouds are made of, when and why this happens, and in what other situation something similar can happen other than at the factory.

The whole process was videotaped while non-verbal observation protocols were also followed.

3.2.3. The Post-Test

Having completed the four stages of activities, a post-test was carried out. Here, the children participated in a test similar to the pre-test interview, in order for the researcher to explore the possible effects of the above-mentioned activities on their way of reasoning.

3.3. Data Analysis

3.3.1. The Pre- and Post-Test

Children's responses to the pre- and post-test were classified into two categories:

(a) Sufficient responses were those that were consistent with the school-level knowledge of water vapor condensation and precipitation in the various phenomena. These were answers in which the variations associated with condensation were described with the appropriate variables and were predicted satisfactorily.

(b) Insufficient responses were those that were incompatible with the school-level knowledge of water vapor condensation and precipitation in the various phenomena. These were answers in which the variations associated with condensation were not described with the appropriate variables and did not adequately predict the changes associated with condensation.

3.3.2. The EDP Analysis

Qualitative data were collected through (a) recordings of both the researcher's narration and children's dialogues during the four stages of activities (duration: 1 h and 30 min), (b) children's drawings after each stage of activities (95 drawings in total), (c) children's non-verbal behavior protocols, and (d) analysis of the video footage. Analysis of the narrative and dialogue was based on the transcripts, with simultaneous documentation of the video footage, drawings, and protocols. The texts were divided into episodes based on themes related to condensation and precipitation [46–48]. The analysis of the episodes was aimed at identifying the critical points at which the formation in children's thinking of mental representations compatible with knowledge learned at school takes place. These critical points were actually the key elements of the precursor model. From this qualitative analysis, the creation of clouds and the processes of evaporation, condensation, and precipitation, as well as precipitation in everyday conditions, emerged as central themes, whose main dimensions will be presented in the following section.

4. Results

4.1. The Pre- and Post-Test

In the following paragraphs, the findings of the pre- and post-test, which qualitatively share the same characteristics, are presented. This data are displayed in a frequency table, while for each response category, characteristic descriptions made by the children are given (Table 1).

Table 1. Frequencies of children's responses to pre- and post-test questions.

	Pre-Test				Post-Test			
	Sufficient		Insufficient		Sufficient		Insufficient	
	Students	**f**	**Students**	**f**	**Students**	**f**	**Students**	**f**
Task 1	2,4,5,7,8,13,14,15	8	1,3,6,9,10,11,12,16,17,18,19	11	1,4,5,7,8,9,10,11,13,14,15,16,17,18,19	15	2,3,6,12	4
Task 2	9,14,15	3	1,2,3,4,5,6,7,8,10,11,12,13,16,17,18,19	16	1,3,4,5,7,8,10,11,14,16,17,18,19	13	2,6,9,12,13,15	6
Task 3		0	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19	19	1,3,4,5,7,8,10,11,14,16,17,18,19	13	2,6,9,12,13,15	6
Task 4	3,6,8,14,17,18	6	1,2,4,5,7,9,10,11,12,13,15,16,19	13	1,3,4,5,6,7,8,9,10,11,13,14,15,17,18,19	16	2,12,16	3
Task 5		0	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19	19	1,3,4,5,6,7,8,9,10,11,13,14,15,17,18,19	16	2,12,16	3
Task 6	3,4,8,11,15,16,18	7	1,2,5,6,7,9,10,12,13,14,17,19	12	3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19	17	1,2	2

4.1.1. What Is a Cloud? What Is a Cloud?

In this question, two categories of responses appeared:

(a) Sufficient responses where children seemed to acknowledge that clouds are created by water. For example, S14, post-test: 'very small droplets that stick'.
(b) Insufficient responses where children described clouds as entities that are artificially created, without making any association with water. For example, S10, post-test: 'white. . . like cotton'.

4.1.2. How Is It Created?

In this question, two categories of responses also appeared:

(a) Sufficient responses where children seemed to recognize that clouds are created by water droplets. For example, S14, post-test: 'very small raindrops, the first cloud becomes rain and falls, and then other clouds join. . . and multiply'.
(b) Insufficient responses where children tended to attribute the creation of clouds to the wind, cotton, ice, snow, or even God.

4.1.3. Do You Know What Condensation Is? Have You Ever Heard the Word Precipitation?

In these questions, two categories of responses also appeared:

(a) Sufficient responses in which children seemed to identify the two physical processes of condensation and precipitation regardless of whether they used these two terms. However, it should be noted that sufficient responses were exclusively recorded during the post-test, and only four children used both terms. For example, S16, post-test: 'the sun warms the sea and steam comes out, cold air blows and the cloud is made' and S3, post-test: 'steam goes over the pot and droplets are made and air is blown. . .'

(b) Insufficient responses where the two physical processes were not recognized at all by children. For example, S17, pre-test: 'when water runs', S3, pre-test: 'something that gets hot', and S12, pre-test: 'that means it's smoke and means we shouldn't follow it somewhere'.

4.1.4. If There Is a Pot of Boiling Water in the Kitchen, What Would Happen on the Kitchen Cabinets? What Would Happen on the Kitchen Windows?

In these questions, two categories of responses also appeared:

(a) Sufficient responses where children were able to detect water vapor or haze on the glass or kitchen cabinets when a quantity of water boils in a pot. For example, S8, pre-test: 'water goes out with the evaporation and gets on the windows'.

(b) Insufficient responses where children did not anticipate evaporation and precipitation on room surfaces. For example, S6, pre-test: 'the water will melt' and S12, pre-test: 'some bubbles are bubbling'.

4.1.5. What If Cold Air Suddenly Blows over the Pot?

In this question, two categories of responses also appeared:

(a) Sufficient responses where children described the creation of a 'cloud' when a pot of water boils in the kitchen and suddenly a mass of cold air is blown out. Quite interestingly, sufficient responses were only recorded in the post-test. For example, S4, post-test: 'it will become steam, it will become droplets, it will become a cloud and go into the sea'.

(b) Insufficient responses where children did not recognize the interaction of hot water vapor with cold air. For example, S9, post-test: '. . .it will cotton remain. . .'

4.1.6. Have You Ever Seen a Factory? Have You Noticed the Chimneys? What Comes Out of There?

In these questions, two categories of responses also appeared. It should be noted here that in the analysis of the results, a distinction was made between 'grey smoke' and vapor, and clouds and 'white smoke'.

(a) Sufficient responses where children recognized the production of smoke and its relationship to the creation of 'clouds'. For example, S6, post-test: 'steam. . . from water, boil water and steam come out. . . it will become a cloud (if cold air blows)'.

(b) Insufficient responses where children did not recognize the relationship between smoke and clouds. For example, S9, pre-test, 'fire... smoke, it (the chimney) takes all the air out and smoke comes in' and S14, pre-test, 'usually smoke comes out when it is very cold. . . smoke comes out of the fire, and they melt things to melt other things'.

4.2. The Four Stages of Activities

The data presented here were derived from the four main stages that followed the Engineering Design Process. The flow and content of the activities are presented with a focus on the critical moments and processes with regard to the transformation of children's mental representations and the construction of the precursor model.

4.2.1. First Stage: Problem

Given the difficulties detected in the pre-test, the learning object emerged in the narration about the story of a child named Paul and the factory. This story was designed to link the water vapor coming out of the boiler with the formation of a kind of cloud. Within this connection, it appeared that the children could easily identify the specific features of the phenomenon, such as the water, the fire in the boilers, the steam, and the formation of the cloud, which was the main object of the activity. Therefore, it seemed that the role of this narration was important as it allowed the necessary connections to be made between the different snapshots, which is a kind of reasoning that refers to a precursor model. The following dialogue, which took place after the narration, clearly shows these connections.

Researcher. How was the cloud created?

S16. From the steam coming out of the chimneys.

S1: From the smoke.

S14: The water became steam and the cloud.

Researcher. So how were they made?

S7: From drops.

During the discussion, some children used their bodies to represent the process and expressed views such as 'in the beginning it was water, then it became steam and finally it went up into the sky and became a cloud' (S14) or that 'it (the cloud) became steam' (S15). At the same time, the researcher moderated this classroom play by re-describing the key elements of the narration and by using formulations to describe the process in which reference was made to the concept of the condensation of water vapor.

4.2.2. Second Stage: Inquiry

In this stage, children were asked to express their thoughts on the following topics: (a) how are clouds created, (b) how they could build a factory that produces steam, (c) how they could try to create their own cloud in class, (d) whether water has to be heated or boiled in order to create a cloud, and (e) what happens in the context of the sea. For this reason, children's initial answers were recorded on the interactive whiteboard in the form of a concept map related to the creation of clouds (Figure 3).

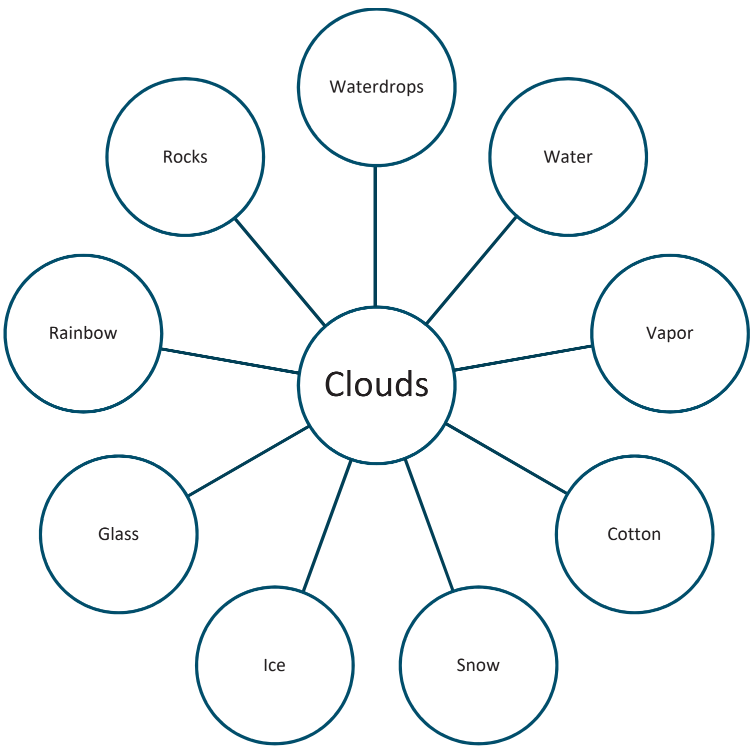

Figure 3. Concept map of children's ideas and solutions.

For these recordings, the children freely expressed their ideas in open discussions without the researcher reacting to what was being said. Thus, the children exchanged views on the materials related to the cloud. During these discussions various entities emerged such as drops, steam, water, cotton, ice, snow, stars, glass, rainbows, stones, etc.

The researcher then asked the children to identify the materials used in the story so that it would be possible to build a similar factory. Trying to respond to this suggestion led many children to select the necessary materials. For example, some children pointed out that the cloud is made 'from very small droplets' (S14) and easily identified the basic materials such as water, fire, and a cauldron. The following dialogue is a typical example of the direction of these discussions with the children. A feature of this dialogue is the actual group discussion as the children follow the thoughts of others and fill in the actual missing elements to complete the description of the necessary experimental set-up.

Researcher. What do we need to build an identical factory?

S3. Gaz. . .

Researcher: What else?

S3. Water. . .

S15. . . .within a pot

S6. Fire. . .

S8. Chimney. . .

Researcher. And what would happen then?

S16. It comes out of the chimney and the air blows and becomes a cloud

Subsequently, the way the children approached the need to 'heat' water was explored, along with whether or not water needs to be boiled in order to create a cloud. In the wider circle of discussion, all of the children seemed to recognize that a pot of water with no heat source would not lead to the creation of a cloud. A typical dialogue is presented as follows:

Researcher. What does it take to create the cloud?

S18. Water and fire

Researcher: And what would happen?

S13. It will boil

S5. It will become steam

Researcher. What if the water didn't boil? Would the factory be able to create clouds?

S15. No

Researcher: Why?

S18. Because it wouldn't boil.

S14. Because there would be no smoke. . . they would not be stunned (drops) to make smoke and create (the cloud).

Finally, the children were asked to discuss what they needed in order to create their own cloud in the classroom. Moreover, they were asked to ask themselves what happens in the context of the sea. The dialogue below shows a typical example of the direction of these exchanges with the children.

Researcher. What could we bring in the classroom in order to create our own cloud?

S3. Pot

S1. Water

S6. Fire

Researcher. I wonder what happens in the sea if it gets hot?

S18. They are leaving (the drops). . .

4.2.3. Third Stage: Designing and Testing

In the third stage, children were asked to individually design how they could make their own clouds and to think about the processes that take place in nature for the creation of clouds. Thus, the children designed their own ideas, although they had the opportunity to discuss them in small groups (Figure 4(4.1,4.4)). Most of the children chose to create their own factory, influenced by the story presented to them, by designing a heat source ('φωτιά') (fire or gas stove), a water ('νερό') container (steamer or cauldron), steam ('ατμός'), and clouds '(σύννεφα') (Figure 4(4.3)).

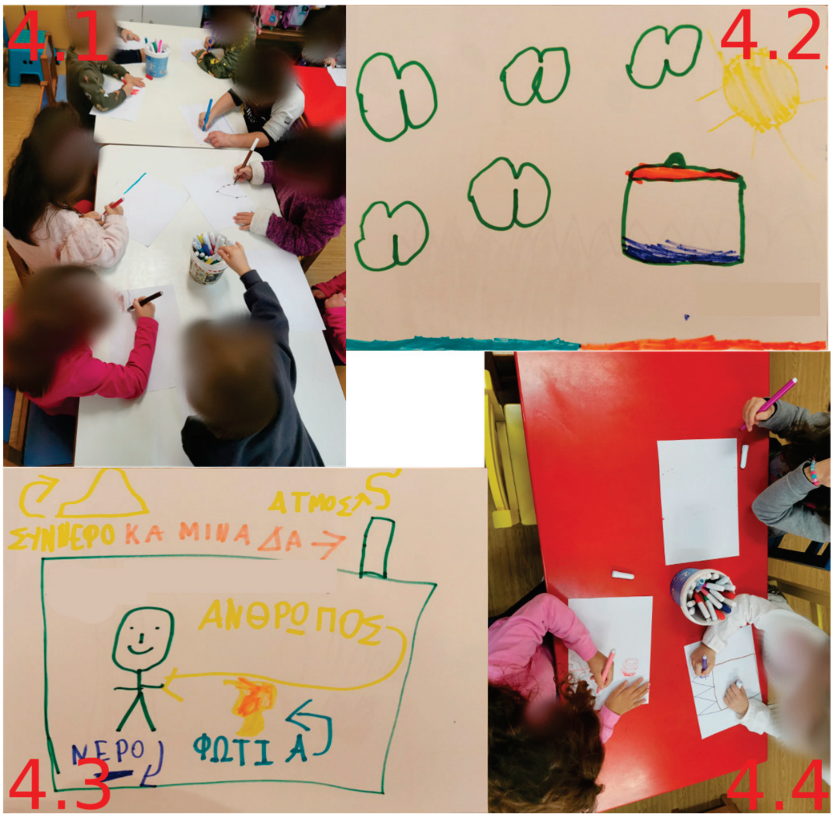

Figure 4. Individual designing and small group discussion.

Only one child drew a pot of water, the sea, and the sun as a heat source in order to show the formation of a cloud over the sea and over a pot of water (in the upper and right part of Figure 4(4.2)). Quite interestingly, most children verbally mentioned air in the description of their drawing but did not capture it in their picture, while no child mentioned water vapor or droplets. Finally, under the guidance of the researcher, the children presented their designs to the class.

Then, the experiments were carried out. The virtual experiment (Figure 2) was implemented by the children who already had a good familiarity with the Scratch 3.0 software. The two experiments of boiling water with gas and a pot were carried out by the researcher in front of the children (Figure 5). In both virtual and real experiments, children were asked to make predictions and confirm or modify them based on the final results of the experiments. First, they tried to predict what would happen in the virtual experiment, in the case of boiling water in the kitchen and then in the case of the sea. Most of the children could not express previous experiences from their daily lives but were able to predict that steam would come out from a pot full of boiling water placed on a stove.

Figure 5. The experiments (**5.1**, **5.2**: The virtual experiment, **5.3**. The experiment of bowling water).

In addition, some children correctly predicted that a kind of cloud will be formed as soon as cold air blows over a pot with boiling water or the sea. The same happened in the case of the sea. These data highlighted considerations that fit into a precursor model for condensation.

Researcher: We put a pot of water in the stove. . . and. . .

S16: It's boiling.

Researcher: And what does it come out?

S11: Bubbles.

S18. Steam. . .

Researcher: Suddenly Paul noticed something in the cupboards of the kitchen and on the glass.

S18: Droplets!!!!!

Researcher: From where?

S16. From the water

Researcher: Suddenly Paul opens the window. What could happen?

S16: The wind is blowing.

S14. Cloud

Researcher: What about the sea?

S16: Steam is coming out.

Researcher: How did drops came out from the sea?

S14: With the sun

Researcher: And then?

S16: It became a cloud

Researcher: How?

S18: The wind blew. . . cold wind. . .

Finally, all children were able to analyze the virtual experiment and describe it in detail, even with reference to drops and water vapor, after the first implementation of the experiment.

In the case of the experiments with water boiling in a small pot next to the classroom window or under a transparent bowl (Figure 4(4.3)), few children were able to predict what would happen to the glass while none of them were able to predict what would happen to the transparent bowl. After the experiment was implemented, each child was able to describe the experiment while the majority of them identified the droplets and water vapor that came from the steam. In addition, some children managed to connect the two experiments as 'the glass becomes blurred like the bowl' (S13).

Researcher: How about we boil some water?

S14: We'll make a cloud.

S3: And we will open the window. . .

During the experiment with the bowl and the pot, initially, the water was made to boil in order to create steam.

Researcher: Can you see the steam?

S8: Yes

S3. Because it is white

Researcher: Can you see the droplets?

S18. No

Researcher: What do you see?

S18. Steam

Later, the bowl was placed in the steam path so that the steam becomes liquid and drops appear on the surface of the bowl.

What happened?

S11: Blurred, as our breath is like air

S18. Small droplets

S14: Sir, shall we all blow it together? (to make a cloud)

Quite interestingly, some children wanted to 'touch' the steam and noticed that as soon as they placed their palms in the steam before it reached the bowl, their hands became wet. At this point, the researcher introduced the terminology 'condensation' and 'precipitation' to describe the experiments. However, none of the children chose to use these terms.

In addition, at this stage, the connection between the gaseous form of water as steam and its liquid form of water vapor within a cloud was made through a music-motor game (Figure 6). In this game, the children took the form of steam with their bodies in the beginning, before later taking on the form of a cloud. The children were able to move freely in the classroom as steam/gas, and had to approach each other and move as a cloud/group as soon as 'cold air' was blowing.

Figure 6. Music-motor game Steam–Cloud.

4.2.4. Fourth Stage: Conclusion and Presentation

In the fourth and final stage, the children were asked to present their findings and conclusions to another class of the school as well as their parents. After a plenary discussion, they chose to make a group poster since they had more experience with this approach. The children freely created their poster and chose to represent the clouds that are created over a factory due to the steam and cold air blowing, as well as the clouds that are created over a lake or the sea. In the posters, important details were emphasized, showing the water vapor, the clouds, and the air. Furthermore, having created the poster, the children divided themselves into the roles of presenter and cameraman in order to film their presentations (Figure 7).

Figure 7. Conclusions and Presentation through a Poster.

In this stage, children were capable of justifying how and when clouds are formed and giving a reasonable explanation of why this happens. The analysis of the recordings showed that the children described and presented the poster in a way that was obviously influenced by their experiences from the previous activities, mentioning detailed information. In particular, children identified that initially 'the sun warms the sea' (S2) and the fire heats the water in the pot, then 'steam comes out with droplets' (S7), and finally, 'the wind blows and clouds are made. . . since the droplets all gather together' (S18). Quite interestingly, one toddler was able to fully describe the process by using the phrase 'steam comes out of the chimney and condenses' (S14) with the sudden cold air.

5. Discussion and Conclusions

In the research presented here, the possibility of transforming mental representations and constructing a precursor model in the thinking of children aged about 5 years for the condensation and precipitation of water vapor was studied. The design of this qualitative research included a pre- and post-test for the recording of mental representations, as well as a structured teaching process consisting of four stages of activities during which multiple forms of pedagogical action were used, completely adapted to the cognitive needs of the children and the organization of the school class.

The first research question was addressed through tasks 1 and 2 in the pre- and post-test. In particular, in the first task, where children were asked to identify the clouds, almost 4/10 of them responded in a correct manner in the pre-test. This percentage was doubled during the post-test. In task 2, where children were asked to describe the conditions for cloud creation, only 3/19 of them gave responses compatible with school knowledge in the pre-test. On the contrary, after the teaching process, 13/19 children were able to satisfactorily describe the creation of clouds in terms of the condensation of water vapor, while frequent references were made to the precipitation of clouds in the form of rain. An important qualitative element of children's thinking here is their constant reference to 'drops', which seems to play a key role in their mental thinking. Indeed, the concept of drops acts as the connecting element of the repeatable continuous cycle of water–clouds–rain, since all these three entities in children's thinking are made up of water drops. This finding is a strong element of a precursor model as drops are an element of children's thinking that allows descriptions while being compatible with school knowledge. These findings are in line with those of other relevant studies [33,36,37].

The second research question was addressed through task 3, where an attempt was made for open discussions about condensation and precipitation. Quite interestingly, in the pre-test, there were no children who were able to propose schemes for describing the phenomena in a way that was compatible with school knowledge. On the contrary, a significant change was recorded in the post-test, as approximately 7/10 children gave answers in which they satisfactorily described the two physical processes and, in some cases, were able to name these processes with terms used in school knowledge. This change is remarkable, not only because it shows that the overall teaching process was well-adapted to the cognitive needs of children, but also because it emerged that the children showed a readiness to reorganize their experiences. These data clearly reinforce the establishment of a precursor model.

The third research question was addressed through tasks 4, 5, and 6, where children's mental representations of condensation in everyday phenomena were explored. In all three tasks, the discussions with children led to the condensation or precipitation of water vapor. In the fourth and sixth tasks, while 3/10 and 4/10 children, respectively, gave responses compatible with school knowledge in the pre-test, this percentage was increased to 8/10 and 9/10 children, respectively, in the post-test. In the fifth task, children were asked what would happen if cold air met water vapor. Here, while no children gave a scientifically accepted response in the pre-test, almost 84% in the post-test were able to describe the precipitation of water vapor in a systematic way.

From the overall research data, it seems that it is possible to some extent to transform young children's initial mental representations into representations compatible with school knowledge. Indeed, it appears that a teaching intervention based on the four levels of the Engineering Design Process, which combines a narrative with the simultaneous performance of critical design experiments, creates a favorable teaching environment for achieving cognitive transformations in young children's thinking. The successful combination of a storytelling approach with the simultaneous organization of simple experiments has been shown to create an effective learning and teaching perspective in thermal phenomena [49,50]. Perhaps, in the context of the Engineering Design Process, it acquires new dynamics which, however, should be substantiated with empirical data for other concepts and phenomena.

The data retrieved from the post-test of the current study highlight that children's mental representations are consistent with school knowledge across all tasks. Indeed, more than half of the children (10/19) gave satisfactory predictions and descriptions in all tasks. The stability of these findings gives a strong indication that children are able to conceptualize entities in their minds that have the characteristics of a precursor model at this age.

However, the study is characterized by specific limitations such as a limited number of participants and an exclusively qualitative nature. Further efforts along the same direction with a larger number of participants and quantitative analyses could shed light on other aspects of the research question. It would also be interesting to address children's mental representations of clouds, condensation, and precipitation of water vapor with participants from different cultural backgrounds to highlight possible differences in the perception of these phenomena.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions.

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References

1. Akerson, V.L. Teaching and learning Science in Early Childhood Care and Education. In *The Wiley Handbook of Early Childhood Care and Education*; Brown, C.P., Benson McMullen, M., File, N., Eds.; John Wiley & Sons, Inc.: Medford, MA, USA, 2019; pp. 355–376.
2. Ravanis, K. Research Trends and Development Perspectives in Early Childhood Science Education: An Overview. *Educ. Sci* **2022**, *12*, 456. [CrossRef]
3. Siry, C.; Trundle, K.C.; Saçkes, M. Science Education during the early childhood years. In *Handbook of Research on Science Education*; Lederman, N.G., Zeidler, D.L., Lederman, J.S., Eds.; Routledge: London, UK, 2023; Volume III, pp. 499–527.
4. Ravanis, K.; Boilevin, J.M. What Use Is a Precursor Model in Early Science Teaching and Learning? Didactic Perspectives. In *Precursor Models for Teaching and Learning Science during Early Childhood*; Boilevin, J.M., Delserieys, A., Ravanis, K., Eds.; Springer: Cham, Switzerland, 2022; pp. 33–49. [CrossRef]
5. Larkin, K.; Lowrie, T. Play, digital play, and play-based learning. In *STEM Education in the Early Years: Thinking about Tomorrow*; Springer Nature: Singapore, 2022.
6. Kastriti, E.; Kalogiannakis, M.; Psycharis, S.; Vavougios, D. The teaching of Natural Sciences in kindergarten based on the principles of STEM and STEAM approach. *Adv. Mob. Learn. Educ. Res.* **2022**, *2*, 268–277. [CrossRef]
7. Kornelaki, A.C.; Plakitsi, K. Thunderbolt hunt. Educational Program for Students from 5 to 9 Years Old in the Archaeological Museum of Ioannina. *World J. Educ.* **2018**, *8*, 87–101. [CrossRef]
8. Sousa, D.; Pilecki, T. *From STEM to STEAM: Integrating the Arts*; Corwin: Newbury Park, CA, USA, 2015.
9. Ioannou, M. Ice Melting in Early Childhood Education: A Case of the Designing and Implementing a STEAM Project about Water State Changes. *Medit. J. Educ.* **2023**, *3*, 164–175. [CrossRef]
10. Hadzigeorgiou, Y. A Study of the Development of the Concept of Mechanical Stability in Preschool Children. *Res. Sci. Educ.* **2002**, *32*, 373–391. [CrossRef]
11. Chachlioutaki, M.-E.; Pantidos, P. Semiotic multiplicities and contradictions in science learning. *Rev. Sci. Math. ICT Educ.* **2023**, *17*, 75–87. [CrossRef]
12. Chachlioutaki, M.-E.; Pantidos, P. Speech and Gesture Complementarity in a Preschooler's Conceptualization of Mechanical Equilibrium. *Educ. Sci.* **2024**, *14*, 338. [CrossRef]
13. Zuazagoitia, D.; Ruiz de Azua, L.; Sanz, J.; España-Diez, S.; López-Puente, M.; Ruiz-González, A. Una propuesta didáctica sobre rampas en educación infantil: La importancia de la intervención docente en el desarrollo de destrezas científicas y construcciones. *Enseñ. Cien.* **2023**, *41*, 11–31. [CrossRef]
14. Canedo Ibarra, S.P.; Gómez Galindo, A.A. Social interaction in the construction of a floating and sinking precursor model during preschool education. In *Precursor Models for Teaching and Learning Science during Early Childhood*; Boilevin, J.M., Delserieys, A., Ravanis, K., Eds.; Springer: Cham, Switzerland, 2022; pp. 53–73.
15. Elmalı, Ş.; Laçin Şimşek, C. Pre-school children's opinions about the concepts of floating and sinking and the effect of in-class interactions on their opinions. *Hacet. Univ. J. Educ.* **2021**, *36*, 227–238.
16. Sesto Varela, V.; Lorenzo Flores, M.; García-Rodeja Gayoso, I. Encouraging the construction of a Precursor Model about air through experimental activities in preschool. In *Precursor Models for Teaching and Learning Science during Early Childhood*; Boilevin, J.M., Delserieys, A., Ravanis, K., Eds.; Springer: Cham, Switzerland, 2022; pp. 111–129.
17. Cain, R.; Lee, V.R. A thermometer for kindergarten data inquiry. In *Constructionism 2020*; Tangney, B., Rowan Byrne, J., Girvan, C., Eds.; The University of Dublin: Dublin, Ireland, 2020; pp. 63–66.
18. Kampeza, M.; Delserieys, A. Acknowledging drawing as a mediating system for young children's ideas concerning change of state of matter. *Rev. Sci. Math. ICT Educ.* **2020**, *14*, 105–124.
19. Konstantinidou, Z.; Brentas, F.; Stamatoglou, M. The connections children develop between science and mathematics: An example of temperature measurement in the kindergarten. *Contem. Math. Sci. Educ.* **2024**, *5*, ep24004. [CrossRef] [PubMed]
20. Pahl, A.; Fuchs, H.U.; Corni, F. Young Children's Ideas about Heat Transfer Phenomena. *Educ. Sci.* **2022**, *12*, 263. [CrossRef]
21. Delserieys, A.; Impedovo, M.A.; Fragkiadaki, G.; Kampeza, M. Using drawings to explore preschool children's ideas about shadow formation. *Rev. Sci. Math. ICT Educ.* **2017**, *11*, 55–69.
22. Gallegos-Cazares, L.; Flores-Camacho, F.; Calderon-Canales, E. Preschool science learning: The construction of representations and explanations about color, shadows, light and images. *Rev. Sci. Math. ICT Educ.* **2009**, *3*, 49–73. [CrossRef]

23. Pantidos, P.; Herakleioti, E.; Chachlioutaki, M.E. Reanalysing children's responses on shadow formation: A comparative approach to bodily expressions and verbal discourse. *Int. J. Sci. Educ.* **2017**, *39*, 2508–2527. [CrossRef]
24. Samara, V.; Kotsis, K. Preschool children's perceptions of the role of light and chlorophyll in plants' photosynthesis. *Int. J. Educ. Innov.* **2020**, *2*, 146–157.
25. Ampartzaki, M.; Kalogiannakis, M. Astronomy in Early Childhood Education: A Concept-Based Approach. *Early Child. Educ. J.* **2016**, *44*, 169–179. [CrossRef]
26. Jelinek, J.A. Children's Astronomy. Shape of the earth, location of people on earth and the day/night cycle according to polish children between 5 and 8 years of age. *Rev. Sci. Math. ICT Educ.* **2020**, *14*, 69–87.
27. Nikolopoulou, A.; Fili, S.; Founta, M.; Starakis, I. Kindergarten students' and pre-service teachers' perceptions regarding the frequency of the Moon's appearance at night. *Int. J. Early Years Educ.* **2024**, *32*, 137–157. [CrossRef]
28. Ioannou, M.; Kaliampos, G.; Fragkiadaki, G.; Pantidos, P.; Ravanis, K. Water state changes and the water cycle in nature: A research review for early childhood education. *AIP Conf. Proc.* **2024**, *3058*, 040032. [CrossRef]
29. Al Jadidi, N.A.; Mohamed, D.A.; Elrefee, E.M. Teaching natural sciences: Simplifying some physics concepts as activities and laboratory tools for kindergarten children. *J. Balt Sci. Educ.* **2022**, *21*, 928–945. [CrossRef]
30. Christodoulakis, N.; Adbo, K. An Analysis of the Development of Preschoolers' Natural Science Concepts from the Perspective of Framework Theory. *Educ. Sci.* **2024**, *14*, 126. [CrossRef]
31. Fleer, M. Scientific Playworlds: A model of teaching Science in play-based settings. *Res. Sci. Educ.* **2019**, *49*, 1257–1278. [CrossRef]
32. Bar, V.; Travis, A.S. Children's views concerning phase changes. *J. Res. Sci. Teach.* **1991**, *28*, 363–382. [CrossRef]
33. Bar, V. Children's views about the water cycle. *Sci. Educ.* **1989**, *73*, 481–500. [CrossRef]
34. Tytler, R. A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: Dimensions of conceptual progression. *Int. J. Sci. Educ.* **2000**, *22*, 447–467. [CrossRef]
35. Cruz-Guzmán, M.; García-Carmona, A.; Criado, A.M. Aprendiendo sobre los cambios de estado en educación infantil mediante secuencias de pregunta–predicción–comprobación experimental. *Enseñ. Cien.* **2017**, *35*, 175–193. [CrossRef]
36. Kambouri-Danos, M.; Ravanis, K.; Jameau, A.; Boilevin, J.M. Precursor Models and Early Years Science Learning: A Case Study Related to the Water State Changes. *Early Child. Educ. J.* **2019**, *47*, 475–488. [CrossRef]
37. Ravanis, K.; Kambouri, M.; Jameau, A.; Boilevin, J.M. Teaching interaction strategies with children 5–6 years in the mental construction of a Precursor Model: The case of water state changes. In *Precursor Models for Teaching and Learning Science during Early Childhood*; Boilevin, J.M., Delserieys, A., Ravanis, K., Eds.; Springer: Cham, Switzerland, 2022; pp. 95–110. [CrossRef]
38. Ahi, B. The effect of talking drawings on five-year-old Turkish children's mental models of the water cycle. *Int. J. Environ. Sci. Educ.* **2017**, *12*, 349–367.
39. Savva, S. Year 3 to year 5 children's conceptual understanding of the mechanism of rainfall: A comparative analysis. *Ikastorratza. e-Rev. Didác.* **2014**, *12*, 1–13. Available online: https://www.ehu.eus/ikastorratza/12_alea/rainfall.pdf (accessed on 8 July 2024).
40. Christidou, V.; Hatzinikita, V. Pre-school children's explanations of plant growth and rain formation: A comparative analysis. *Res. Sci. Educ.* **2006**, *36*, 187–210. [CrossRef]
41. Jelinek, J. The ability of children aged 6 and 9 years, respectively, to detect errors in a narrative based on incorrect information about evaporation in the water cycle. *Forum Pedag.* **2022**, *13*, 355–365. [CrossRef]
42. Malleus, E.; Kikas, E.; Marken, T. Kindergarten and primary school children's everyday, synthetic, and scientific concepts of clouds and rainfall. *Res. Sci. Educ.* **2017**, *47*, 539–558. [CrossRef]
43. Fragkiadaki, G.; Fleer, M.; Ravanis, K. Understanding the complexity of young children's learning and development in science: A twofold methodological model building on constructivist and cultural-historical strengths. *Lear. Cult. Soc. Inter.* **2021**, *28*, 100461. [CrossRef]
44. Georgantopoulou, A.; Fragkiadaki, G.; Kaliampos, G.; Ravanis, K. Constructing a Precursor Model for clouds and rain in the thinking of 4–6-year-old children. In *Precursor Models for Teaching and Learning Science during Early Childhood*; Boilevin, J.M., Delserieys, A., Ravanis, K., Eds.; Springer: Cham, Switzerland, 2022; pp. 131–154. [CrossRef]
45. Kikas, E. Children's thinking. Clouds, rain, and rainbow in children's explanations. *Electron. J. Folk.* **2010**, *44*, 113–130. [CrossRef]
46. Guba, E.G.; Lincoln, Y.S.; Denzin, N.K. *Handbook of Qualitative Research*; Sage: Thousand Oaks, CA, USA, 1994.
47. Creswell, J.W. *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*; Sage: Thousand Oaks, CA, USA, 2014.
48. Robson, C.; McCartan, K. *Real World Research*; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2016.
49. Kaliampos, G.; Pantidos, P.; Ravanis, K. Transforming 5-year-old children's mental representations of melting: A storytelling approach. *AIP Conf. Proc.* **2023**, *2595*, 040012. [CrossRef]
50. Ampatzidis, G.; Ergazaki, M. Can the history of the balance of nature-idea inform the design of narratives for highlighting general aspects of nature of science? *Rev. Sci. Math. ICT Educ.* **2021**, *15*, 77–88. [CrossRef]

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Article

Inquiry-Based Activities with Woodlice in Early Childhood Education

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Abstract: This study aims to describe the implementation of a teaching sequence where preschool-age children participate in activities related with woodlice. Although there is extensive literature on inquiry-based activities, most studies have been conducted in higher educational stages. Data were collected though audio and video recordings of the sessions, which have then been transcribed. The children participated in research activities in which they had no difficulty in posing hypotheses and making predictions. In relation to the experimental design, we observed difficulties in understanding the purpose of the experiment and how to reach conclusions from the experimental results. From the results of this study, we can conclude that children from an early age can engage in inquiry activities where they are given opportunities to make predictions, formulate hypotheses, and, with the help of the teacher, plan simple experiments to test their ideas.

Keywords: preschool-age children; case study; inquiry-based approach; scientific practices; living being woodlice

1. Introduction

There is growing recognition that science can be a particularly important domain in early childhood, building a foundation for future scientific understanding, as well as developing critical skills and positive attitudes towards learning [1].

It has been noted that children have an innate curiosity about things related to science, and well-designed science activities provide them with a structured way to explore the world to satisfy their curiosity [2]. Moreover, there are various studies that show the importance of carrying out science activities from an early age to promote scientific practices [3]. Well-designed science activities can stimulate thinking, reasoning ability, and contribute to children's cognitive development [4,5]. Likewise, early exposure to scientific content and practices can promote favorable attitudes toward science and contribute to children's cognitive development by giving them the opportunity to plan, predict, make inferences, and confront cognitive conflicts [1].

Some teachers and researchers believe science activities for children should focus more on developing creativity or fostering skills, such as learning to ask questions or make observations, since scientific concepts are considered too advanced for children to comprehend. This perspective leads us to think that for children to participate in inquiry activities, the teacher must create spaces where children can carry out explorations with little intervention from the teacher. However, while it makes sense that a goal of teaching science at an early age is not the acquisition of sophisticated scientific concepts, we do believe that science activities should promote the construction of precursor models of scientific concepts. When we talk about precursor models, we refer to the idea of the mental model. We currently know that from an early age, children build their own mental models about the world around them and revise these models as they access new information [6]. The construct of the mental model refers to a mental representation created by subjects based on their innate predispositions and their previous experiences in order to predict, describe, or explain facts or phenomena [7]. The idea of a precursor model is a fruitful approach to observing children's cognitive progress. Precursor models are generated in the educational context and can be built under certain teaching conditions from an early age; they are the first step in the construction of more sophisticated models [8]. They are models compatible with scientific knowledge, since they are built based on certain elements included in the scientific model, but they have a limited range of applications [9,10]. These are models that constitute the basis for subsequent constructions [11]. We can imagine that a precursor model constitutes a kind of "conceptual tricycle" that children can handle to think and generate new knowledge, compared to adult models, characterized by being more complex and difficult to execute and, to continue with the metaphor, they could be associated with "conceptual trucks". The design of well-planned interventions, in which adequate empirical data are provided, is crucial so that precursor models can be developed [10].

Eshach and Fried [2] refer to the importance of carrying out science activities at an early age that give children the opportunity to build references for scientific concepts by making observations, predictions, making inferences, and being able to discuss and try to explain and interpret what happens. The term "inquiry-based activities" is used to refer to science activities where children are given the opportunity to make observations and predictions. Thus, "inquiry learning" refers to educational activities in which, either individually or in groups, students investigate a phenomenon. Inquiry activities typically follow a series of steps: the formulation of a question or problem, the development of hypotheses, the design and conduct of experiments or investigations, the collection and analysis of data, and the formulation of conclusions based on the evidence obtained. Inquiry-based activities can vary in their degree of openness, depending on who poses the question to be investigated, whether the teacher or the students, who formulated the hypotheses, who planned the experimental design, and so on.

In this work, we wanted to differentiate inquiry-based activities, where the teacher's role would facilitate meaningful discussions to advance knowledge in an experimental environment from exploratory activities, where the teacher's role would only be to generate spaces with materials where children can explore and experiment on their own [12]. The inquiry-based activities are more structured activities with greater teacher involvement. Through inquiry-based activities, students formulate questions, interpret data, and coordinate evidence with theories, thus developing intellectual skills that enable them to construct new knowledge [13]. Studies from cognitive psychology have shown that inquiry-based activities stimulate brain development [14]. In addition, inquiry-based activities contribute to the development of scientific reasoning by providing opportunities to ask questions, make predictions, carry out inquiries, and begin to interpret data and coordinate evidence with theories [13].

However, we must consider the extent to which inquiry-based activities are suitable for early childhood education and whether or not the cognitive demand of these activities is too high [3]. Although there is much research available to support inquiry-based activities, there has been some doubts about how to fit them with children aged three to five. There is no agreement on which activities would be most appropriate for early childhood education. Although studies have been carried out to characterize the demand for science activities in relation to the cognitive abilities of the students [15], there are no studies that allow us to clearly say what preschool-age children are capable of doing when they engage in inquiry activities or what they are capable of doing with the support that the teacher can provide. In fact, by analyzing the literature, we can think that age limits what children can do and learn in science activities, and we can reach the conclusion that science activities for early childhood education should be limited to developing skills with less cognitive demand such as learning to observe, compare, or find similarities and differences. However, there is evidence that children can carry out inquiry-based activities that involve carrying out investigations or experimentation to test ideas despite the greater cognitive demand, and it seems that children are able to use empirical evidence to formulate explanations. One of the skills that children must manage is causal reasoning. Some authors consider that such reasoning is underestimated due to its dependence on domain-specific prior beliefs, thus masking children's reasoning ability [16].

Some of the evidence that has been obtained in other studies [17] contrasts with the finding that many primary school children are not very skilled in designing experiments [18,19]. As Hsin et al. observe, science learning involves a variety of scientific practices, and some may be more challenging for young children [20]. For example, planning research seems to require greater cognitive demand than other scientific practices such as conducting systematic observations (see, e.g., [21,22]). However, there is little research that has explored what instructional strategies teachers use to support children (3–5 years old) in inquiry-based activities [20].

It is crucial to know more about children's abilities regarding questioning, planning and designing experiments, identifying relevant evidence, making hypotheses and predictions, and identifying variables. Despite its importance, empirical studies on the outcomes of scientific learning in preschool age are rare [23,24]. Above all, we must know more about the achievements of children when implementing inquiry-based activities in collaboration with an adult and in collaboration with their peers. There are many ways to try to build knowledge on this topic. One possible way is to describe and analyze what happens in a classroom when implementing inquiry activities with younger children. Introducing science in early childhood education is an extremely delicate task and requires exploring and understanding children's perceptions, knowing the key aspects of the scientific content, and being able to design appropriate interventions and learning environments [25].

In this study, activities on isopods were implemented. Specifically, the teaching sequence dealt with a terrestrial crustacean commonly known as a woodlouse or pill bug. Carrying out activities with living beings in early childhood education can be beneficial as long as it is carried out ethically, with care towards the animals and environment. Activities with living things provide children with experiences that help them better understand the natural world. Interacting with live animals stimulates their curiosity and connection with nature and fosters respect and empathy towards other living beings, contributing to the development of ethical values and care for the environment. Observing, caring for, and feeding small animals helps children develop responsibility and cooperation. Additionally, working with living things can be easily integrated into interdisciplinary activities that span areas such as science, mathematics, language, and the arts. Given the alarming loss of biodiversity, it is essential to educate about the value of the diversity of organisms and learn to value and know local organisms [26]. Young children are especially interested in living organisms. Woodlice or pill bugs are attractive and interesting, they are harmless and easy to collect, and they provide an excellent opportunity for children to learn about invertebrates [27–29].

The interest of this work lies in the fact that it shows how children in early childhood education develop inquiry activities in a classroom context with the help of the teacher.

Research Questions

This work presents a case study that aimed to describe the implementation of a proposal where preschool children make observations and design experiments. The activities in which the children participated involved a terrestrial isopod crustacean belonging to the Armadillidiidae family. This kind of crustacean is known in colloquial language as a woodlouse or pill bug. Children investigated aspects related to the morphology and behavior of woodlice by taking data, making drawings, completing diagrams, or designing objects. During the activities, the teacher helped them detail the observations with some questions such as: Do woodlice have eyes? How many legs do they have? How would we know if woodlice prefer dry or humid places? The aim of this study is to know to what extent preschool children can engage in inquiry-based activities. Specifically, the main research questions that this study aims to answer are the following: What are children's ideas about woodlice? To what extent do children participate in the inquiry activities about woodlice? To what extent are they involved in the activities where they have to make predictions about the behavior of woodlice? To what extent are they involved in the activities where they have to plan and design an experiment? To what extent are they able to draw conclusions from the experience?

2. Materials and Methods

This study involved a qualitative methodological approach and, in particular, constitutes a case study. This approach is characterized by being descriptive and qualitative in nature and is recommended when little is known about the phenomenon to be analyzed [30]. Case studies can intensively address a unit of analysis that may consist of a single student, a teacher, or a class [31]. Thus, a case study aims to describe, know, and understand a phenomenon of interest within its own context [32] and allows the exploring of individual experiences, providing a deeper understanding of social interactions and offering detailed information about particular cases [33]. In this work, participant observation was chosen, given the level of involvement of the person collecting the data.

2.1. Context and Participants

This research was developed in a rural school where the second cycle of early childhood education (3–6 years) is taught. The school belongs to a public grouped rural school. It is an organization model that is implemented in rural areas where the student population is small and dispersed. This model allows resources to be optimized and offers advantages in terms of socialization since students of different ages share resources and learning experiences. In the school where this study was carried out, there is a pedagogical approach that adapts to the particular needs of the community and activities are developed that promote the knowledge and appreciation of the natural environment and local culture. Since there are few students, personalized attention is favored. In this school, it is common to work on projects and coordinate work between different schools.

In the classroom where the study was carried out, the teacher started from the interests of the students and the characteristics of the environment to achieve greater motivation among the students. The person who taught the class is a trainee teacher who is studying a professional Master's degree. At the time that the teaching sequence was implemented, a total of ten preschool-age children, five girls and five boys, attended this school. As shown in Table 1, the participants' ages ranged between three and five years old. To ensure the anonymity of the children, their real names were replaced by pseudonyms. The three-year-old participants were children who responded very well to the activities proposed by the teacher. In terms of the ethical considerations, it is important to mention that we requested the informed consent of the parents for the participation of each child.

Table 1. Participants sorted by age.

Participants	Age
Carmen, Casto, Carlos	5 years old
Bea, Brais, Breogán	4 years old
Ana, Ara, Antón, Alex	3 years old

2.2. Description of the Teaching Sequence

The teaching sequence took place in a dialogic context where the teacher and the children spoke, acted, and thought about the phenomena, and where social interaction was one of the main factors in the construction of knowledge, framed in a socio-constructivist perspective [34]. It was implemented with a total of seven 50 min sessions.

We selected woodlice because they are unique, abundant, and harmless animals that children can handle. Woodlice are terrestrial crustaceans belonging to the order of isopods. The body is divided into the head, thorax (pereion), and abdomen (pleon). On the head, you can see the antennae, maxillipeds, and eyes. The thorax has seven segments. They have seven pairs of legs (isopods) and two uropods in the last segment of the abdomen.

These animals have gill or pseudogill respiration, depending largely on water, which is why they always live in shady and humid places such as under stones, logs, etc. Regarding their diet, they are detritivorous animals. They feed on the remains of living beings, mainly plants, and are important in the recycling of materials in the soil [35].

The teaching sequence is described in more detail in Table 2. In the first activity, children had to find cards in the classroom. The cards had a photograph of a woodlouse. The teacher asked the children questions about woodlice. Then, the children went out to the yard in search of woodlice. In the second session, the teacher asked questions about the morphology of woodlice and introduced new terms. "What parts does the woodlouse's body have?" "How many legs does it have?" "Will it have eyes?" Subsequently, the children worked in small groups using magnifying glasses, making more systematic observations and recording them. In the third session, the preschoolers completed drawings of pill bugs to work on symmetry. In the fourth session, the children had to design and carry out an experiment to study the behavior of woodlice in front of light. In the fifth session, the preschoolers had to design and carry out an experiment to study the behavior of woodlice in humidity. The sixth activity was about applying ideas about the parts of the woodlouse and, at the same time, working on fine motor skills when building a cardboard woodlouse. In the seventh activity, the children were given the opportunity to apply the ideas built through experimentation when designing a habitat for woodlice.

Table 2. An overview of the activities of teaching intervention.

Session	Learning Objectives and Overview
No. 1 What do we know about woodlice?	This activity is aimed at the children's knowledge. First, a series of cards with photos of woodlice are hidden in the classroom and the children must find them. The teacher with the children asks the children questions about the woodlice that appear on the cards. "What appears in the photo?" "Have you ever seen it?" "Where do you think they live?" "How many legs do they have?" "What do they eat?" "Do they have eyes?" Later, the children go out to the yard in search of woodlice. When they return to the classroom they discover a box with woodlice. The woodlice obtained in the yard are introduced. Children handle them freely and observe them. After interacting with the pill bugs, they leave them in the box and make a drawing. Materials: Cards with photographs of woodlice and a box.
No. 2 What are woodlice like?	This activity aims for children to make systematic observations and identify the head, eyes, antennae, thorax, abdomen, legs, and uropods of woodlice. The teacher asks questions such as: What are woodlice like? What parts does the body have? How many legs do they have? Can you see their eyes? In small groups, the children make observations with the magnifying glass. The teacher introduces new terms and the children, with the help of the teacher, place the labels with the names in the corresponding places on a drawing of a woodlouse. In addition, they make drawings of the woodlice. Materials: Woodlice, magnifying glasses, drawings, and labels.
No. 3 Symmetry of woodlice	This activity is intended for children to apply terms introduced in the previous session. In this activity, they work individually, completing a sheet where a drawing of half of a woodlouse appears, having to complete the symmetrical half using a mirror. Materials: Sheet and mirrors.
No. 4 Behavior of woodlice in front of light	This activity is intended for students to design an experiment, formulate predictions, make observations, and draw conclusions. It is about learning the behavior of woodlice in front of light. The teacher asks questions such as: "Do they prefer bright or dark places?" "How can we know?" First, they design the experience, recording the predictions in tables. Afterwards, they place the woodlice in places with different light conditions and wait a few minutes. Then the children write down the observations and draw their own conclusions. Materials: Shoe boxes and cartons.
No. 5 Behavior of woodlice in front of humidity	This activity is intended for children to design an experiment, formulate predictions, make observations, and draw conclusions. It is about learning the behavior of woodlice in humidity. The teacher asks questions such as: "Do they prefer dry or humid places?" "How can we know?" First, they design the experience, recording predictions in tables. Afterwards, they place the woodlice in places with different humidity conditions and wait a few minutes. Then the children write down the observations and draw their own conclusions. Materials: Cardboard boxes, kitchen paper, and a spray bottle with water.
No. 6 Mock-up	This activity is intended for students to apply ideas about the parts of a woodlouse. In a group, they build a cardboard woodlouse. Materials: Cardboard and pencils.
No. 7 Building a terrarium for pill bugs	This activity is intended for students to apply ideas about the behavior of woodlice in certain environmental factors. The teacher asks questions to check what the children learned during the teaching intervention and gives them the opportunity to apply these ideas to design a habitat for the woodlice.

2.3. Data Collection and Data Analysis

In this paper, information was collected, in the form of a classroom diary, from the observations of each session, and the most significant contributions of the participants were written down. In addition, two sessions (session 1 and session 5) were audio and video recorded, and later transcribed. Only sessions for which we had informed consent to capture audio and video were recorded. We have selected the sessions that could provide us with the most valuable information to answer the research questions. The transcriptions were written verbatim to preserve the essence of the speech. The excerpts that are included in the Results and Discussion section have been translated from Spanish and Galician. The students speak both languages fluently. To analyze the discourse, conventional turns were taken as a unit of analysis. A turn began when a person took the floor in a conversation and ended when another person took the floor.

In order to ensure the reliability and validity of this interpretive study, the triangulation of both data and researchers was used [36,37]. Data triangulation refers to the confrontation of different sources of data from the study. In this case, the information collected was a classroom diary and the transcriptions of the audio and video recordings. In relation to the triangulation of research, the transcripts were analyzed individually by the authors and, subsequently, a common reflective analysis of the analysis of all these records was carried out.

3. Results and Discussion

In the following lines, significant events of the discursive interactions between the teacher and the children are presented. Similar to other works [38,39], the communicative interactions are presented in three columns, which refer to the speaking turns, the transcribed dialogue, and the analysis of the interventions in order to describe the intentionality or meaning of each intervention.

3.1. Session 1

In Session 1, the teacher divided the participants into two groups. Group 1 was made up of Casto (5 years old), Bea (4 years old), Brais (4 years old), Alex (3 years old), and Ana (3 years old). Group 2 was made up of Carmen (5 years old), Carlos (5 years old), Breogán (4 years old), Ara (3 years old), and Antón (3 years old).

As shown in Table 2, during this session, the teacher asked questions to find out the children's ideas about woodlice. Since woodlice are familiar creatures for some children, some children were already able to express their ideas and comment on experiences.

3.1.1. Discourse Analysis in Group 1

In Group 1, a total of 128 contributions were made during Session 1 and 61 contributions were made by the teacher. Casto (5 years old) made 24 contributions. Bea (4 years old) made 13 contributions, Brais (4 years old) intervened 10 times, Alex (3 years old) intervened 18 times, and Ana (3 years old) barely participated; she only spoke on two occasions.

When the teacher asked the children what they thought the living beings that appear in the photo were, Casto (5 years old) said that they were larvae, that they live in oak trees and in holes, and that they eat leaves and soil.

Turn	Speaker	Statement	Analysis of Interaction
1	Teacher	What do you think they are?	The teacher tries to encourage the children to make their ideas explicit.
2	Casto	Bugs.	Casto identifies woodlice with insects.
3	Teacher	Ah! And do they have another name?	The teacher tries to encourage the children to make their ideas explicit.
4	Casto	(...) Larvae.	Casto relates the activity to one they previously completed with the ants.

Bea (4 years old) stated she does not like woodlice. At another point, she said that woodlice eat logs. She believed that they live in logs and that at night, they run away and curl up in a ball. In another comment, she said: "They walk and then they turn into little balls and we think it's a ball to hit (...) And then we catch them, we throw them and that hurts them, and they get hurt and we have to take them to their mummy bug".

Brais (4 years old) said that woodlice live in a small house that is not colored. Later, he said: "They are strong (...) because they eat a lot of food".

Alex (3 years old) commented that he saw the bugs in the cinema, because they were on the screen, and pointed out that the bugs are first big, and then small, and then a ball.

Ana (3 years old) barely participated. She spoke twice, although the teacher tried to encourage all the children to engage in the conversation. At the end of the session, the teacher insisted that Ana participate. Casto intervened to explain the intention of the questions to Ana.

Turn	Speaker	Statement	Analysis of Interaction
110	Teacher	Only you remain. Tell me something Ana. What do you think they are? What do you think they eat?	The teacher tries to encourage Ana to participate.
111	Casto	What do you think. It's not what it is.	Casto realizes the importance of how questions are phrased to encourage participation.
113	Teacher	(. . .) Aren't you telling me anything, sweetheart? You tell me later.	The teacher tries to encourage Ana to participate.
114	Ana		She nods.

3.1.2. Discourse Analysis in Group 2

In Group 2, a total of 82 contributions were made during Session 1 and 38 were made by the teacher. Carmen (5 years old) made 20 contributions, Carlos (5 years old) did not speak, Breogán (4 years old) intervened 7 times, Ara (3 years old) intervened 8 times, and Antón (3 years old) intervened 9 times.

When the teacher asked the children what they thought the living beings that appear in the photo were, Carmen (5 years old) mentioned that she did not know what woodlice are. She said she had never seen them. She believed they live in a hole or a cave. She thought they can eat dirt and water. She stated she did not know anything about woodlice.

Turn	Speaker	Statement	Analysis of Interaction
1	Teacher	Let's talk a little about these bugs. Do you know what they are?	The teacher tries to encourage the children to make their ideas explicit.
2	Carmen	I don't know.	She claims not to recognize woodlice.
3	Ara	I do.	She claims to recognize woodlice.
4	Carmen	Worms?	She identifies woodlice with worms.
5	Ara	They are bugs.	She identifies woodlice with insects.

Breogán (4 years old) pointed out that he did see woodlice on the road and that they are great. He does not believe they eat dirt, but they do eat stones. He said they are small, and he likes them. Ara (3 years old) thought woodlice are bugs. She believed they eat dirt, but not stones. Antón (3 years old) said that pill bugs are called snails and that they are bugs. According to him, woodlice live on the soil, they are called snails, they eat stones, sand, and dirt, and also toys and mats, and they are small.

Turn	Speaker	Statement	Analysis of Interaction
68	Teacher	(. . .) Where do you think they live? Have you ever see them?	The teacher tries to encourage the children to make their ideas explicit.
71	Antón	(. . .) I think they eat stone and sand and dirt, and also toys, and also mats.	He lists what he thinks woodlice eat.

3.1.3. Discussion

In the first session of the teaching sequence, the children showed great enthusiasm for working with living beings in the classroom. To obtain an idea of the participation of the children and the teacher, we counted all the contributions that took place. In Table 3 we can see the number of contributions by each participant in each session. As shown in Table 3, the number of children's contributions was more than 50% of the total interventions in each session, although not all participated equally. In Group 1, a total of 128 contributions were made during Session 1 and 61 contributions were made by the teacher. In Group 2, a total of 82 contributions were made during Session 2, 38 of which were made by the teacher.

Table 3. Participant contributions in each working group during the development of Session 1 and Session 5. N_{GX} = Total number of contributions in group X.

Participants	Session No. 1 N_{G1} = 128 N_{G2} = 82	%	Session No. 5 N_{G1} = 111 N_{G2} = 199 N_{G3} = 187	%
Teacher G1	61 (128)	47.60	54 (111)	48.64
Teacher G2	38 (82)	46.34	95 (199)	47.73
Teacher G3			83 (187)	44.38
Casto (5 years old)	24 (128)	18.75	20 (111)	18.01
Carmen (5 years old)	20 (82)	24.30	61 (187)	32.62
Carlos (5 years old)	0 (82)	0	9 (199)	4.52
Bea (4 years old)	13 (128)	10.15	21 (187)	11.22
Brais (4 years old)	10 (128)	7.81	15 (111)	13.51
Breogán (4 years old)	7 (82)	8.53	51 (199)	25.63
Alex (3 years old)	18 (128)	14.06	40 (199)	20.10
Ana (3 years old)	2 (128)	1.56	22 (187)	11.76
Ara (3 years old)	8 (82)	9.75	10 (111)	9.00
Antón (3 years old)	9 (82)	10.97	12 (111)	10.81

The teacher's spoken interactions were primarily in the form of questions and, in some cases, to correct the behavior of a child or to encourage them to participate. The questions fulfilled different functions, such as starting the conversation: "What do you think these little bugs are?" They were also used to encourage the children to pay attention to the characteristics of woodlice: "Are they all the same?" On other occasions the questions were intended to connect with their experiences: "Have you ever see them?" They also tried to connect with the preschoolers' emotions: "Do you like them?" The questions also fulfilled the function of activating the children's knowledge: "Do you know where they live?" "And what will they eat?" Also, so that they could express themselves more effectively: "And do they have another name?"

As shown in Table 3, the children who participated the most were the five-year-old children, Casto, from Group 1, and Carmen, from Group 2. Furthermore, in relation to the children's contributions, we can say that they differ quite a bit in their commentary. The children were not very clear about what woodlice were called, and used terms such as bugs (the older ones), snails, and worms (the smaller ones) to refer to woodlice. When asked where woodlice live, the children responded that they think they live in oak trees, on logs, in the grass, in the dirt, and in holes. We could consider these statements to be synthetic or naturalistic explanations [40]. As for food, they believed that they can eat dirt, logs, and grass.

Some of the 4-year-old children used anthropomorphic expressions. For example, Bea said: "And then we catch them, we throw them and that hurts them, and they get hurt and we have to take them to their mummy bug". Another 4-year-old child, Brais, mentioned: "They live in a little red house." These anthropomorphic expressions are characteristics of the preoperational stage according to Piaget [41]. When a young child is said to have anthropomorphic reasoning, it means that he or she tends to attribute human characteristics to objects, animals, or phenomena that do not possess them.

The three-year-old children tended to establish syncretic explanations, also characteristic of the preoperational stage. For example, Alex said the following about woodlice: "First it's big, then it's small, and then it's a ball". Syncretism is closely related to the way in which children relate events and objects in their environment, tending to group objects or events based on superficial characteristics or emotional associations rather than on logical or rational criteria. This means that they can make connections between events that have no real logical connection [41].

3.2. Sessions 2–4

In Session 2, the children were highly involved in observation activities. The only difficulty regarding terminology was the term uropods, although some children learned it right away. The older children had no difficulty writing the names of the parts of the woodlouse. The little ones needed the help of the older ones.

In Session 3, symmetry was worked on, as had occurred in previous proposals about ants and ladybugs. This activity gave the children the opportunity to apply the terminology that had been introduced in the previous session. Three-year-old pupils needed more help than older students.

In Session 4, a large group activity was carried out where they had to design an experiment to find out if pill bugs prefer light or darkness. In this activity everyone was very excited to do an experiment. This activity was led by the older children who proposed the experimental design. Although the planning was led by the five-year-old children, the teacher considered that the three- and four-year-old children understood the purpose of the research. There are doubts as to whether the little ones understood the result of the experiment. One girl did not understand that woodlice like the dark better since there were two in the light and eight in the dark. She said: "Eight like the light better, but two like the dark better". She understood the results as concrete and literal data and this may be due to a lack of probabilistic thinking [15]. These aspects will be discussed in greater depth later.

3.3. Session 5

In the fifth session, an activity was implemented where children had to design an experiment to find out the behavior of woodlice in humidity.

In this session the teacher divided the participants into three groups. Group 1 was made up of Casto (5 years old), Brais (4 years old), Ara (3 years old), and Antón (3 years old). Group 2 was made up of Carlos (5 years old), Breogán (4 years old), and Alex (3 years old). Group 3 was made up of Carmen (5 years old), Bea (4 years old), and Ana (3 years old).

3.3.1. Discourse Analysis in Group 1

In Group 1, a total of 111 contributions were made during Session 5 and 54 were made by the teacher. Casto (5 years old) made 20 contributions, Brais (4 years old) made 15 contributions, Ara (3 years old) made 10 interventions, and Antón (3 years old) commented 12 times.

First, they completed a recapitulation of the experiment they had carried out as a whole class about the behavior of woodlice in front of light.

Turn	Speaker	Statement	Analysis of Interaction
1	Teacher	What experiments did we do yesterday?	The teacher asks the children about what they did in the previous experiment.
2	Casto	Whether or not they like the darkness.	Casto remembers the purpose of the experiment.
6	Teacher	Do they like light or darkness?	The teacher asks the children about the conclusions of the experiment they completed in the previous session.
8	Antón	The light.	He mentions, as a conclusion of the experiment, that woodlice prefer light.
9	Casto	The darkness.	He mentions, as a conclusion of the experiment, that woodlice prefer darkness.
10	Teacher	But what happened yesterday in the experiment?	The teacher asks the children about the result of the experiment they completed in the previous session.
11	Antón	Many in the dark part and two in the light part.	Antón remembers the result, but is not able to reach a conclusion.

Subsequently, the teacher suggests doing research to find out if woodlice prefer humid or dry environments.

Turn	Speaker	Statement	Analysis of Interaction
29	Teacher	What will they like more, being in a dry or humid area?	The teacher asks the children to express their ideas.
30	Antón	Be wet.	He makes a prediction.
34	Ara	Entourages.	She makes a prediction.
35	Teacher	(. . .) We have to mark what we think they will like on the chart.	The teacher instructs each child to cover the prediction on the sheet.
38	Teacher	Casto, that's to cover later when we do the experiment. Now, we may think one thing, but another may happen. We have to check if the predictions come true.	The teacher focuses attention on the task they have to perform, indicating what to cover the predictions and explains the role of the experiment that will allow the ideas to be tested.

Then, the teacher encouraged the children to think about how to design the experiment.

Turn	Speaker	Statement	Analysis of Interaction
56	Teacher	Anton, what idea do you have? How can we tell if they like it moister or dryer?	The teacher tries to encourage Antón to participate in the planning of the experiment.
57	Antón	We put everything wet.	He makes a proposal.
58	Teacher	And so how do we know?	The teacher questions Antón's idea.
59	Brais	No! No!	He disagrees with Antón's idea.
60	Casto	Maybe they like it dry.	Casto intervenes to question Antón's idea.
61	Ara	No, wet, wet.	Ara intervenes to question Casto's idea.
62	Maestra	How do we do it, Ara?	The teacher tries to encourage Ara to participate in the planning of the experiment.
63	Ara	Wet and dry.	Ara modifies Antón's proposal by pointing out the need to put both a dry and a humid area in.

Afterwards, the children placed the woodlice in places with different humidity conditions. They continued talking and after a few minutes, they returned to look at where the woodlice were.

Turn	Speaker	Statement	Analysis of Interaction
86	Teacher	Let's see where they are placed. Where are they?	The teacher directs the conversation so that the children focus their attention.
87	Casto	It seems that in the wet part.	Casto makes an observation.
91	Teacher	How many are there in the wet part?	The teacher asks Casto to give more details about his observation.
92	Antón	Three.	Brais and Ara also count three woodlice.
93	Teacher	Well, we point out in the observation chart that there are three in the wet part. If in total we had four and in the wet zone there are three, how many will there be in the dry zone?	The teacher gives instructions for collecting observation data and challenges the children with a new question.
109	Teacher	So, what did they like more. humid or dry?	The teacher asks the children to draw conclusions from the experiment.
110	Brais	The wet!	He draws a conclusion from the experiment.
111	Antón	The wet!	Antón shares Brais' conclusion.

The following lines summarize the development of the session for this group. Casto (5 years old) and Antón (3 years old) considered that the woodlice would like to be in the wet area more, but there was no agreement since Ara (3 years old) and Brais (4 years old) believed that they would like to be in the dry area better. The participants covered the prediction sheet according to their hypotheses with the teacher's help. At this point we consider it relevant to clarify that in this study, when we refer to predictions, this refers to when children make statements about what will happen when performing the experiment. Prediction often derives from a hypothesis, from an idea to be tested, describing an observable result that must occur if the hypothesis is correct. The teacher showed them the material: a cardboard box, paper, and a spray bottle with water. To test their hypotheses through experimentation, Casto (5 years old) proposed moistening the box so that the woodlice would survive. The teacher reminded him that the purpose of the experiment was to find out if they prefer a humid or dry environment. Casto (5 years old) did not seem to understand the purpose of the experiment and insisted on moistening the entire box so that the woodlice would survive. Other children, Ara and Antón, also wanted to put all the wet paper in the box. They also did not seem to understand the purpose of the experiment. However, when the teacher asked them again, they said that they had to put one part wet and the other dry.

Afterwards, they discussed how many woodlice to place and decided to put four woodlice. After waiting a few minutes, they made the observations. They counted three pill bugs in the wet part and one in the dry part. Casto (5 years old), without the teacher's help, understood the result of the experiment and concluded that they prefer humidity. Brais (4 years old) and Ara (3 years old) described the result indicating that there were more woodlice on the wet side. Antón said there were more woodlice on the dry side. When the teacher asked what the woodlice prefer, a humid or dry environment, Brais and Ara answered that they like the humid area better. However, we are not sure that they would have reached the same conclusion on their own.

3.3.2. Discourse Analysis in Group 2

In Group 2, a total of 199 contributions were made during Session 5 and 89 were made by the teacher. Carlos (5 years old) made nine contributions, Breogán (4 years old) made 51 contributions, and Alex (3 years old) commented 40 times, but many of his contributions were off-task. At one point in this session, Alex required the presence of another teacher who intervened to keep Alex's attention. There were six interventions from the other teacher. In total, both teachers made 95 utterances.

A few moments before the activity, Breogán (4 years old) started a conversation with the teacher while observing the woodlice. Alex and Carlos also participated.

In the following episode, Breogán (4 years old) discovered how the woodlice move and how they form a ball. The teacher told the children how to pick up woodlice so as not to hurt them.

Turn	Speaker	Statement	Analysis of Interaction
1	Breogán	Hey! They can walk around here. They are very fast.	He makes an observation about the movement of woodlice.
2	Teacher	They are very fast, yes.	The teacher shares Breogán's observation.
3	Breogán	Hey! This is where they are trying to escape!	He makes an observation about the movement of woodlice.
6	Teacher	Yes, they like to be free more. When we finish, we'll release them in the patio.	The teacher makes a comment about the behavior of the woodlice.
7	Breogán	(. . .) Hey! There's a ball inside here. Did they ball up?	Breogán observes how a woodlouse takes the shape of a ball.
8	Teacher	They would be scared! You have to handle them carefully!	The teacher guides Breogán on how to handle the woodlice.
9	Alex	Now I'm going to take them carefully.	Alex indicates that he is going to follow the teacher's instructions regarding handling the woodlice.

Then, the teacher took advantage of Breogán's (4 years old) contributions to make a brief recapitulation of what the children had learned.

Turn	Speaker	Statement	Analysis of Interaction
11	Breogán	Look how big! Hey! This one tickles me. Hey! There is a bigger one! I hadn't realized there was a bigger one!	He shows amazement at the size of the woodlice.
12	Alex	Look teacher! Look at it!	Alex shows amazement when he observes the legs of the woodlice.
13	Teacher	Yes. It has legs. Look how well we can see its legs. What parts does the woodlouse have?	The teacher takes the opportunity to review the body parts of a woodlouse.
14	Alex	Antennae!	Alex indicates a part of the body of woodlice.
21	Teacher	What else do they have?	The teacher asks the children about the body parts of a woodlouse.
22	Breogán	Eyes!	He indicates a part of the body of woodlice.
23	Teacher	Okay, the he. . .	The teacher helps children remember the parts of a woodlice.
24	Breogán	Head!	He indicates a part of the body of woodlice.
25	Teacher	Very good! The tho. . .	The teacher helps children remember the parts of a woodlice.
26	Breogán	Thorax!	He indicates a part of the body of woodlice.
28	Teacher	Very good! Ab. . .	The teacher helps children remember the parts of a woodlice.
29	Breogán	Abdomen!	He indicates a part of the body of woodlice.
32	Teacher	Very good! What were the names of the peaks below them?	The teacher helps children remember the parts of a woodlice.
33	Breogán	Uropods!	He indicates a part of the body of woodlice.
35	Alex	Uropods.	Alex indicates a part of the body of woodlice.
37	Breogán	And they have stripes down the back.	He indicates a part of the body of woodlice.

Afterwards, the teacher asked the children what they had learned from the previous experiment they had completed regarding the behavior of woodlice in front of light.

Turn	Speaker	Statement	Analysis of Interaction
41	Teacher	What did we learn from the experience we did yesterday?	The teacher asks the children what they learned in the previous experiment.
47	Alex	Some went to the light and many remained in darkness.	Alex describes what he observed regarding the behavior of woodlice in front of light.
48	Teacher	What did they like most?	The teacher asks the children to remember the conclusions of the experiment.
49	Breogán	Darkness.	He draws, as a conclusion of the experiment, that woodlice prefer darkness.
40	Teacher	Carlos, what did the woodlice like the most?	The teacher asks Carlos to remember the conclusions of the experiment.
51	Carlos	Mmmm. . . Eat.	He gives an answer unrelated to the conclusions of the experiment.
52	Teacher	Carlos, what did they like more, darkness or light?	The teacher rephrases the question to help Carlos draw a conclusion.
53	Carlos	Darkness.	He draws, as a conclusion of the experiment, that woodlice prefer darkness.

The teacher continued the session by asking the children questions about the places where the woodlice live, and whether they prefer wet or dry soil. The children presented their ideas as hypotheses and began to cover the prediction sheet with the help of the teacher.

Turn	Speaker	Statement	Analysis of Interaction
66	Teacher	(. . .) How do you think they will like the soil? When it rains and is wet, or when it doesn't have any water?	The teacher asks the children to express their ideas.
67	Breogán	When it doesn't have any water.	He makes a prediction.
68	Teacher	Alex, how do you think they will like it?	The teacher encourages Alex to make a prediction.
69	Alex	Mmmm. . .Wet.	Alex makes a prediction.
70	Teacher	Carlos, dry or wet? How will the woodlice like it best?	The teacher encourages Carlos to make a prediction.
71	Carlos	Dry.	He makes a prediction.
72	Breogán	I'm going to mark. . . this one.	Breogán refers to what he is going to record on the prediction sheet.
73	Teacher	This is dry and this is wet. What do you think?	The teacher gives information to Breogán about how to cover the sheet and encourages him to make a prediction.
74	Breogán	Dry.	He makes a prediction.
75	Teacher	Well, mark here.	The teacher explains to Breogán how to cover his prediction on the sheet.
76	Alex	To me, wet.	Alex makes a prediction.

The children believed that when they finished the prediction sheet, they finished the activity and began to get up. The teacher asked them if they remember the experiment they performed in the previous session. Breogán remembers that they carried out an experiment to find out if woodlice prefer light or darkness.

Turn	Speaker	Statement	Analysis of Interaction
81	Teacher	Let's do an experiment.	The teacher presents the activity.
91	Teacher	What experiment can we do to find out if they like it wet or dry? (. . .) Let's see Alex, what experiment can we do?	The teacher tries to encourage Alex to participate in the planning of the experiment.
92	Alex	Wet.	Alex seems to suggest moistening the cardboard box.
93	Teacher	But how can we check it? We have a box, some papers and a spray bottle with water. Think about how we did the experiment yesterday.	The teacher guides the design of the experiment.
94	Breogán	We put a bug here.	Alex suggests putting a woodlouse in the cardboard box.
95	Teacher	Okay, but if we put a bug here, how do we know if it likes it more dry or humid? What do we have to put for it to choose?	The teacher guides the design of the experiment.
96	Alex	Water!	Alex suggests putting water in the cardboard box.
99	Teacher	And where do we put the water?	The teacher encourages Alex to make his experimental design proposal more specific.
100	Alex	Here, here, here.	Alex refers to the cardboard box.
101	Teacher	Throughout?	The teacher encourages Alex to make his experimental design proposal more specific.
102	Alex	Here only.	Alex suggests putting water in just one part of the box.

Alex (3 years old) realized that in order for the woodlice to choose, he had to put water on only one side. Later, the children discussed how to place the paper, how to moisten it, and how many woodlice they were going to use. Alex (3 years old) placed the filter paper at the bottom of the cardboard box, moistened half of it with water and placed the woodlice inside. They took a break and returned to observe the results of the experiment.

Turn	Speaker	Statement	Analysis of Interaction
167	Teacher	Let's count how many there are on the wet side and on the dry side.	The teacher directs the conversation so that the children focus their attention.
168	Carlos	Yeah!	He shows a good attitude towards the task.
169	Teacher	How many are on the wet side?	The teacher asks the children to make observations.
170	Breogán	Two.	Breogán makes an observation.
171	Alex	Two.	Alex makes an observation.
174	Teacher	Look at these, one, two, three. . . How many are there on the wet side?	The teacher suggests that the children make observations again.
175	Breogán	Dang! I should have marked on the other side.	By comparing his response during the prediction phase with the observations, Breogán realizes that his hypothesis was wrong.
176	Teacher	No, you did very well! You thought woodlice liked the dry side, but doing the experiment you discovered that they like the wet side. Do you see how many things we can learn by doing experiments?	The teacher reminds Breogán that the purpose of experimentation is to test hypotheses.
186	Teacher	Where were there more?	The teacher asks the children to remember their observations.
187	Breogán	On the wet side.	Breogán remembers an observation regarding the behavior of woodlice in humidity.
188	Teacher	Where were there more, Carlos?	The teacher encourages Carlos to participate.
189	Carlos	Wet.	Carlos remembers an observation regarding the behavior of woodlice in humidity.
190	Teacher	What results did we obtain from the experiment?	The teacher asks the children to draw conclusions from the experiment.
191	Breogán	Not dry! Wet!	Breogán draws a conclusion from the experiment.
196	Alex	Wet!	Alex draws a conclusion from the experiment.

The following lines summarize the development of the session for this group. At the beginning of the session, the teacher started a conversation while the children made observations of the woodlice. In this conversation, Carlos (5 years old) greeted the woodlice and mentioned the uropods. He said that eating is what woodlice like the most. Breogán (4 years old) mentioned the eyes, head, thorax, abdomen, and uropods, and as a result of observation, he discovered that they had stripes on their back. Alex (3 years old) mentioned antennae and uropods.

Next, the teacher asked them what they remembered from the previous session. Carlos (5 years old) remembered that the woodlice liked the dark better. Breogán (4 years old) remembered that the purpose of the experiment was to know if they like light, and remembered as a result and conclusion that they preferred darkness. Alex (3 years old) was able to describe the results: "Some went to the light and many stayed in the dark". However, it seems that he was not able to draw a conclusion.

The teacher asked the children a question: "How do you think they will like the soil better?" The question was not very well formulated and the children gave arbitrary answers. The teacher asked the question again: "How do you think they will like the soil? When is it raining and wet, or when is there no water at all?" They then began to formulate hypotheses about which woodlice like more, dry or moist soil. Carlos (5 years old) and Breogán (4 years old) indicated that they would prefer the dry soil more, and Alex (3 years old) indicated that they would prefer the wet soil. The teacher then told them that they were going to do an experiment. The teacher showed them the material: a cardboard box, paper, and a spray bottle with water. She mentioned the experiment they carried out in the previous session and asked them to think about what experiment they could do to find out if woodlice preferred wet or dry soil. Alex (3 years old) said they like it wetter, so the teacher asked how she could check it. She pointed out the material they had prepared. Breogán (4 years old) pointed out that they needed a bug. The teacher continued asking questions. Alex (3 years old) pointed out that they needed water and that they should put water only on one side. In relation to the design of the experiment, Carlos (5 years old) commented only to say that he was going to give the woodlice a kiss. Breogán (4 years old) understood that there needed to be a dry part and a wet part, and thought that many woodlice should be put in the box, not just one. Alex (3 years old) considered it enough to put a single woodlouse in the box. After Breogán's correction (4 years), he preferred adding multiple. Regarding the results, Carlos (5 years old) was able to indicate the result by pointing out that there were more woodlice in the wet area. Breogán (4 years old) realized that his hypothesis was wrong: "Dang! I should have marked on the other side." He pointed out that there were more pill bugs on the wet side. The teacher took the opportunity to explain to Breogán that he did it very well, and that by doing the experiment, he discovered what the woodlice like the most. Alex (age 3) also pointed out that there were more woodlice on the wet side. In this session, everyone seemed to have come to the conclusion that the woodlice preferred the wet side.

3.3.3. Discourse Analysis in Group 3

In Group 3, a total of 187 contributions were made during the Session 5 and 83 were made by the teacher. Carmen (5 years old) made 61 contributions, Bea (4 years old) made 21 contributions, and Ana (3 years old) intervened 22 times.

The teacher began the session by asking what the children learned from the experiment they had carried out in the previous activity.

Turn	Speaker	Statement	Analysis of Interaction
1	Carmen	Teacher, what do we have to do?	She requests information about the task.
2	Teacher	We are going to do an experiment like yesterday's. Did you like yesterday's experiment?	The teacher introduces the activity and ask the children to remember what happened in the experiment they had carried out to study the behavior of woodlice in front of light.
3	Carmen	Yeah!	She shows a good attitude towards the task.
4	Ana	Yeah!	She shows a good attitude towards the task.
6	Carmen	Look, teacher, what happens is that it likes both, the sun and also black.	Carmen points out that woodlice prefer dark and light environments equally.
7	Teacher	Well, I think they liked one of the two more, because they were almost all on one side of the box.	The teacher reminds the children of the result of the experiment they had carried out to study the behavior of woodlice in front of light.

Turn	Speaker	Statement	Analysis of Interaction
8	Carmen	In black, but they like everything the same.	She remembers that there were more woodlice in the darkness, but she does not seem to be able to draw a conclusion.
9	Bea	But one liked the sun.	She remembers that one woodlouse preferred the light environment.
10	Teacher	One yes, but almost all of them on which side were they?	The teacher asks the children to remember what happened in the experiment they had completed to study the behavior of woodlice in front of light.
11	Carmen	In the sun. . .	Carmen points out that woodlice prefer light environments.
12	Teacher	Where, Carmen?	The teacher encourages Carmen to think again about her answer.
13	Carmen	In the dark, now give me that sheet. . .	Carmen points out that woodlice prefer darkness.

Subsequently, the teacher began a brief conversation that served as a recapitulation of what was learned about the morphology thus far.

Turn	Speaker	Statement	Analysis of Interaction
14	Teacher	First let's go over the parts. What parts did the woodlice have?	The teacher takes the opportunity to review the body parts of a woodlouse.
15	Carmen	The horns! Oh no. . .	She tries to remember the body parts of a woodlouse.
16	Bea	The antennas!	She rectifies Carmen's response.
17	Teacher	What do they have there? The he. . .	The teacher helps children remember the parts of a woodlice.
18	Bea	Head!	She indicates a part of the body of woodlice.
19	Carmen	And the eyes!	She indicates a part of the body of woodlice.
20	Bea	The eyes!	She indicates a part of the body of woodlice.
21	Teacher	What did they are here big?	The teacher helps children remember the parts of a woodlouse.
24	Carmen	The thorax and. . .	She indicates a part of the body of woodlice.
25	Teacher	Lower and smaller?	The teacher helps the children remember the parts of a woodlouse.
26	Carmen	The abdomen.	She indicates a part of the body of woodlice.
27	Teacher	Very good! Phenomenal! Now more difficult. Two little beaks below that started with u.	The teacher helps children remember the parts of a woodlouse.

Afterwards, the teacher introduced the activity that they were going to carry out in this session, which consisted of designing an experiment to study the behavior of woodlice in humidity.

Turn	Speaker	Statement	Analysis of Interaction
55	Teacher	(. . .) What else can we know about the place where the woodlice live? We know they like the dark.	The teacher asks the children about the behavior of woodlice.
58	Bea	In the darkness and in the light one.	She states that woodlice like light and darkness equally.
66	Teacher	(. . .) What would you like more, that the soil is wet or that it is dry?	The teacher encourages child to express her ideas about the behavior of woodlice in humidity.
67	Carmen	Wet!	She makes a prediction.
68	Teacher	What do you think Ana?	The teacher encourages Ana to express her ideas.
70	Ana	Dry.	She makes a prediction.
71	Teacher	Ana thinks it likes it drier. What do you think, Bea?	The teacher encourages Bea to express her ideas.
72	Bea	Wet.	She makes a prediction.
73	Teacher	Okay, Bea thinks she likes it wetter. Carmen, what do you think?	The teacher encourages Carmen to express her ideas.
74	Carmen	Mmmm, wet.	She makes a prediction.
75	Teacher	Okay Carmen, well we mark wet. Where do we mark wet?	The teacher instructs the children on how to cover the prediction sheet.
82	Carmen	I have a clue, when it's sunny, it's dry, and when it's rainy and it gets dark, it's wet. Wet.	She relates rain to darkness because she mentions that woodlice will like wet things because it will be dark. She makes a prediction.

After formulating and writing down the hypotheses, they began to plan the experimental design.

Turn	Speaker	Statement	Analysis of Interaction
96	Teacher	So how are we going to know if they like it more? Wet or dry? What do you think we can do?	The teacher tries to encourage the children to participate in the planning of the experiment.
97	Carmen	Well, we put wet here, and dry here.	She participates in the design of the experiment.
98	Teacher	Ana, I like the idea. Do you think it will work?	The teacher tries to encourage Ana to participate in the planning of the experiment.
99	Ana	Yeah.	She agrees with Carmen's suggestion.
102	Carmen	Yes, but we have a doubt. Because if the wet has drops. . .	Carmen thinks they have a problem with the design of the experiment.
104	Carmen	And how do we do it then?	She shows doubts about how to design the experiment to test their ideas.
105	Teacher	But what about the drops.	The teacher asks the children to clarify what the problem is with the design of the experiment.
106	Carmen	Well, they are going to the dry side. . .	She makes a prediction about the behavior of woodlice against humidity.
107	Teacher	I don't know. We try. Place the filter papers well because the woodlice previously escaped underneath.	The teacher gives instructions on how to place the materials to be used in the experiment to prevent the pill bugs from escaping.
108	Carmen	Like this?	She requests approval from the teacher.
109	Teacher	Yes, perfect.	The teacher approves Carmen's action.
110	Bea	Me too?	She requests to participate in the placement of the materials.
111	Teacher	Help Carmen place. Well, now what do we have to do?	The teacher suggests Bea collaborate with Carmen.

Next, the teacher asked the children to make predictions about what they thought was going to happen.

Turn	Speaker	Statement	Analysis of Interaction
150	Teacher	What do you think is going to happen?	The teacher asks the children to think about what is going to happen.
151	Ana	In the dry.	She makes a prediction about the behavior of woodlice against humidity.
152	Teacher	Okay later we check. Bea and you?	The teacher asks the children to think about what is going to happen.
153	Bea	In the wet.	She makes a prediction about the behavior of woodlice against humidity.
154	Carmen	And I also. Let's see when they choose.	She makes a prediction about the behavior of woodlice against humidity and suggests carrying out observations.

Finally, the teacher then encouraged the children to look to see what happened.

Turn	Speaker	Statement	Analysis of Interaction
155	Teacher	I think we can now look.	The teacher encourages the children to make observations.
156	Ana	Be careful, they are going to climb.	She suggests carrying out observations carefully to prevent the woodlice from escaping.
158	Carmen	They're still choosing, I think.	She suggests waiting to make observations.
160	Carmen	That's why they go that way. They are not calm.	She believes that woodlice are not calm.
161	Bea	I think they like the wet one better. The dry, only one.	She observes how a greater number of woodlice prefer a humid environment.
163	Carmen	One, two, three, four, five and, in the dry, zero.	She counts the number of woodlice in the humid and dry environment.
167	Carmen	One, two, three, four and five.	She counts the number of woodlice in the humid environment.
168	Teacher	Ah! Look, it's in the dry. Five in the wet and one in the. . .	The teacher encourages children to make observations.
169	Carmen	In the dry.	She observes that there is only one woodlouse in the dry environment.
170	Teacher	So, which one do they like more?	The teacher asks the children to draw conclusions from the experiment.
171	Carmen	The wet.	She draws a conclusion from the experiment.
172	Bea	The wet.	She draws a conclusion from the experiment.
173	Teacher	Well, we put on the dry side how many there were. We draw one on the dry side.	The teacher gives instructions on how to cover the sheet.
178	Carmen	Teacher, I'm done.	She provides information about the status of the task.
179	Teacher	Okay, which one did they like the most, Ana?	The teacher asks Ana to draw conclusions from the experiment.
180	Ana	The humid one.	She draws a conclusion from the experiment.

The following lines summarize the development of the session for this group. At the beginning of the session, the teacher started a conversation pointing out that they were going to do an experiment similar to the one they had completed the previous day. The teacher asked the children if they remembered the experiment. Carmen (5 years old) remembered the results of the experiment, but did not agree with the conclusions they drew: "Look, teacher, what happens is that it likes both, the sun and also black (. . .). There was more in the black but they like everything the same". Bea (4 years old) agreed with Carmen (5 years old) and said "one likes the sun".

Later, the teacher prepared to review the parts of the woodlice. The first thing Carmen (5 years old) said was "the horns", but her answer was immediately rectified by Bea who said "antennas". Bea (4 years old) and Carmen (5 years old) pointed to the head and eyes. Carmen (5 years old) pointed to the thorax and abdomen. With the teacher's help, they remembered the term "uropods". Ana (3 years old) said that woodlice had hands. The teacher corrected her and then she named the legs. Ana and Bea said woodlice have four legs. With the teacher's help, they said fourteen.

Then, the teacher asked them where woodlice live. Bea (4 years old) believed that they live in darkness and light. The teacher asked: "What will the place where they live be like? Will they like the ground to be there? Dry or wet?" Carmen (5 years old) thought woodlice like the night better. Ana (3 years old) said darkness. They marked possible hypotheses. Bea (4 years old) and Carmen (5 years old) thought they would prefer wet soil and Ana (3 years old) thought they would like dry soil. Carmen (5 years old) pointed out a clue: "when it's sunny, it's dry, and when it's rainy and it gets dark, it's wet". Next, the teacher showed them the material: a cardboard box, paper, and a spray bottle with water. She mentioned the experiment they carried out in the previous session and asked them to think about what experiment they could do to find out what woodlice preferred, when the soil was wet or dry. Carmen (5 years old) suggested how to design the experiment by putting a wet part and a dry part in the box. Ana (3 years old) and Bea (4 years old) thought it would work. Carmen (5 years old) suggested that each of them pick up three woodlice, but Ana (3 years old) did not want to pick them up with her hands. They placed in six woodlice and waited. After a while, they went to look, but Carmen (5 years old) pointed out that the woodlice were still choosing. The children waited a little longer and returned to count the number of woodlice in each part. There were five woodlice on the wet side and one on the dry side. They were all able to point out the results and they all seemed to conclude that woodlice preferred humidity.

3.3.4. Discussion

In the fifth session of the teaching sequence, a group activity was carried out where the children had to design an experiment to find out the behavior of woodlice against humidity. The children found the two sessions where they had to design experiments very interesting and they were a topic of conversation for several days.

To get an idea of the participation of the children and the teacher, we have counted the contributions. In Table 3, we can see the number of contributions by each participant in each session. The number of children's contributions was more than 50% of the total, although not all participated equally. As shown in Table 3, almost all the children spoke more in this session than in the first session. In Group 1, a total of 111 contributions were made during Session 5, 54 of which (48.64%) were made by the teacher. In Group 2, a total of 199 contributions were made during this session, 95 of which (47.73%) were made by the teachers. In Group 3, a total of 187 contributions were made during the Session 5, 83 of which (44.83%) were made by the teacher.

The teacher's statements were generally in the form of questions. Sometimes the teacher's contributions were to direct the activity: "First let's review the parts". At some moments, she gave them instructions on the procedure to follow or how to treat the woodlice with care. In some interactions she encouraged the children when they responded correctly: "Wow, Breogán! Shake my hand, champion! Very good!". The questions fulfilled different functions, such as starting the conversation: "What experiment did we do yesterday?" Through questions, the teacher encouraged the children to remember the experiment they did in the previous session: "Did they like the light or the dark?" It also encouraged thinking: "We have to think first". Contributions such as "But how can we check it?" or "Now we have to think about how we can do it" encourage children to articulate their thoughts and clearly specify what they needed to do. In the experimental design, the teacher helped the children, but following the ideas that they were proposing: "Shall we put the water in everything? Let's look at where they are placed!". The teacher encouraged the children to look at the results and draw conclusions for themselves: "So what do you like best?".

As shown in Table 3, the children who participated the most were Carmen (5 years old) in Group 3 and Breogán (4 years old) in Group 2.

In the fifth session, Casto (5 years old) and Breogán (4 years old) remembered the purpose of the experiment they had carried out in the previous session and the conclusion they had reached. They remembered that the conclusion was that woodlice like darkness. At first, other participants, among which were Brais (4 years old), Ara (3 years old), Antón (3 years old), and Alex (3 years old), did not remember the conclusion. Carmen (5 years old) remembered the experiment, but was not at all convinced of the conclusion and she said: "Look, teacher, what happens is that they both like the sun and also black". The same thing happened to Bea (4 years old) who said: "But someone likes the sun".

Children were able to formulate hypotheses and make predictions about the behavior of woodlice towards humidity and the preference for a wet or dry habitat. Casto (5 years old), Carmen (5 years old), Bea (4 years old), and Alex (3 years old) indicated that woodlice would like moist soil more, while Brais (4 years old), Ara (3 years old), and Carlos (5 years old) predicted that they would like dry soil better.

In relation to the experimental design, Casto initially did not seem to understand the purpose of the experiment because he believed that the objective was for the woodlice to survive, which is why he wanted to moisten the entire box. The same thing happened to Antón (3 years old) and Ara (3 years old) who wanted to get everything wet. They did not seem to understand the purpose of the experiment. Carmen (5 years old) and Brais (4 years old) understood that there needed to be a dry part and a wet part, and they suggested how to do it. Bea (4 years old) and Breogán (4 years old), Alex (3 years old), and Ana (3 years old) also understood that they needed both a dry part and a wet part.

All the children agreed that the result of the experiment was that there were more woodlice on the wet side, except Antón (3 years old), who said that there were more on the dry side. Breogán (4 years old) realized that his hypothesis was wrong. For Bea, the result was that five woodlice liked the humidity, and only one liked dry environments. In general, all of them seemed to come to the conclusion that woodlice like humidity.

According to these results, the children presented certain difficulties in understanding the purpose of the experiment and how to reach conclusions from the experimental results, as observed when they were asked about the experiment they carried out in the previous session with the aim of finding out if the woodlice prefer the light or the darkness. Lorch et al. noted out that students show a better understanding of variable control if only one variable at a time is offered [42]. In this work, we see how children were able to formulate hypotheses and make predictions about the behavior of woodlice in the face of humidity. Children, in general, recognize the variable that needs to be investigated and how to do it. This is in line with the results of Cook et al. who consider that preschool children already recognize how to isolate variables in a simple context with few variables to investigate [16]. In general, they were able to recognize the results of the experiment and, furthermore, they were able to contrast their predictions with observations. Some difficulties were also observed in reaching conclusions from the experimental results. These results would be in agreement with the results of Piekny et al. who have shown that preschool children already have a basic ability to evaluate evidence and a basic understanding of experimentation [43]. The findings showed that the ability to evaluate evidence is already well developed at the age of four, and increases steadily and significantly over time as long as the covariation pattern is perfect.

3.4. Sessions 6–7

In the sixth session, the children made a model of a woodlouse, enhancing fine motor skills and the artistic field. This activity also gave children the opportunity to use terms referring to the morphology and apply ideas and terms that they had learned in the observation activities.

The seventh session was a recapitulation activity of what was learned. It consisted of a conversation with the children where they were given the opportunity to apply the ideas they had learned about the morphology and habitat of woodlice to the construction of a terrarium.

4. Conclusions

This paper describes how children (aged 3 to 5) and the teacher dealt with work in the classroom. They built ideas and practiced scientific skills through empirical experience and dialogue with others by engaging in inquiry activities with woodlice. The first session, in which an exploration activity for activating ideas was implemented, and the fifth session, in which an inquiry activity was performed, were analyzed in more depth.

At the beginning of the teaching sequence, the children had the opportunity to express their knowledge about woodlice, making reference to their name, habitat, food, etc. The teacher's interactions were mainly in the form of questions to activate the children's knowledge. We can say that, in general, the children were involved in the activity, although not all participated to the same extent. In relation to the children's ideas about woodlice, it should be noted that the children did not know their proper name. They referred to them as bugs, and the younger children referred to them as snails or worms. Despite not knowing their name, the children did express correct ideas about the food and habitat of the woodlice. As has been pointed out in other papers, explanations that refer to certain aspects of children's approaches to living beings often reflect anthropomorphic reasoning [44]. Some of the 4-year-old children used anthropomorphic expressions attributing human characteristics to objects, animals, or phenomena that do not possess them. On the other hand, the three-year-old children tended to establish syncretic explanations, tending to group objects or events based on superficial characteristics or emotional associations instead of on logical or rational criteria [41]. In addition, the children were involved in the observation activities and showed interest in learning the names of the parts of the woodlice such as the head, the antennae, the eyes, the legs, or the uropods, in addition to learning more ideas about the habitat and the feeding. These last ideas could help the construction of a precursor model about living beings [45].

The children were involved in inquiry activities in which they had to make predictions, plan an experiment, obtain results, and draw conclusions about the behavior of the pill bugs. In this paper, the fifth session was analyzed in more detail, where they carried out an inquiry activity on the behavior of woodlice against humidity. The teacher interacted with the children by asking questions and encouraging them to express and record their ideas and predictions, encouraging them to think about the experimental design to test ideas, and to record the results and draw conclusions for themselves. In the activity where they have to make predictions about the behavior of the woodlice in relation to humidity, the children presented certain difficulties in understanding the experimental design and the purpose of the experiment and how to reach conclusions from the experimental results. The children were able to formulate hypotheses and make predictions about the behavior of pill bugs against humidity and record the predictions with the help of the teacher. In general, they were able to recognize the results of the experiment. Furthermore, they were able to contrast their predictions with observations.

As seen in this paper, children are involved in inquiry activities. Children can make predictions, formulate hypotheses, and, with the teacher's help, are able to plan a simple experiment to test their ideas. Furthermore, in simple experiments with a single variable, they are able to understand the results and draw conclusions. On the other hand, these types of activities allow children to learn to find answers to scientific questions through experimentation.

In this paper, information was collected through a classroom diary, in which the observations of each session were noted down, and video and audio recordings of two sessions (Session 1 and Session 5). The analysis of the discourse from the first session and the classroom diary allowed us to answer the question about the children's ideas about woodlice. The analysis of the speech and the classroom diary of three groups from the fifth session allowed us to answer the questions related to the children's participation in the inquiry-based activities. A limitation of the study is the lack of data for the discourse analysis of all activities in the sequence, which would have provided a more robust and complete view of the implementation of the teaching sequence.

Educational Implications

As noted by Lazonder et al., in any early-childhood education classroom, there must be time for free play and exploratory activities, but we must not lose sight of the importance of implementing more structured and more demanding inquiry-based activities for children and also for teachers [46]. Furthermore, carrying out these types of activities with woodlice allows children to become familiar with these small living beings and can help fear, repulsion, and biophobia disappear. In this study, only some children showed some rejection of woodlice at the beginning of the activity. This may be due to the rural context in which the participants of this study live. On the other hand, the teacher's role is essential in providing opportunities for all children to participate in inquiry-based activities. In this study, interaction in a heterogeneous group (3–5 years) was beneficial for all children and this was due, in part, to the skill of the teacher who encouraged the participation of all children.

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References

1. Gelman, R.; Brenneman, K. Science learning pathways for young children. *Early Child. Educ.* **2004**, *19*, 150–158. [CrossRef]
2. Eshach, H.; Fried, M.N. Should science be taught in Early Childhood? *J. Sci. Educ. Technol.* **2005**, *14*, 315–336. [CrossRef]
3. Hsin, C.T.; Wu, H.K. Implementing a project-based learning module in urban and indigenous areas to promote young children's scientific practices. *Res. Sci. Educ.* **2023**, *53*, 37–57. [CrossRef]
4. French, L. Science as the center of a coherent, integrated early childhood curriculum. *Early Child. Res. Q.* **2004**, *19*, 138–149. [CrossRef]
5. Worth, K. Science in early childhood classrooms: Content and process. In *Early Childhood Research and Practice*; Collected Papers from the SEED (STEM in Early Education and Development) Conference; University of Northern Iowa: Cedar Falls, IA, USA, May 2010.
6. Kuhn, D.; Pease, M. Do children and adults learn differently? *J. Cogn. Dev.* **2006**, *7*, 279–293. [CrossRef]
7. Greca, I.M.; Moreira, M.A. Mental models, conceptual models, and modelling. *Int. J. Sci. Educ.* **2000**, *22*, 1–11. [CrossRef]
8. Ravanis, K. La construction de la connaissance physique à l'âge préscolaire: Recherches sur les interventions et les interactions didactiques [La construcción del conocimiento físico en la edad preescolar: Investigaciones sobre intervenciones e interacciones didácticas]. *Aster* **2000**, *31*, 71–94.

9. Canedo-Ibarra, S.P.; Castelló-Escandell, J.; García-Wehrle, P.; Morales-Blake, A.R. Precursor models construction at preschool education: An approach to improve scientific education in the classroom. *Rev. Sci. Math. ICT Educ.* **2010**, *4*, 41–76.
10. Ravanis, K.; Koliopoulos, D.; Hadzigeorgiou, Y. What factors does friction depend on? A socio-cognitive teaching intervention with young children. *Int. J. Sci. Educ.* **2004**, *26*, 997–1007. [CrossRef]
11. Weil-Barais, A. What Is a Precursor Model? In *Precursor Models for Teaching and Learning Science during Early Childhood*; Boileivin, J.M., Delserieys, A., Ravanis, K., Eds.; Springer: Cham, Switzerland, 2022; Volume 55, pp. 11–32.
12. Chaille, C.; Britain, L. *The Young Child as Scientist: A Constructivist Approach to Early Childhood Science Education*, 3rd ed.; Allyn & Bacon: Boston, MA, USA, 2003.
13. Chan, C.; Burtis, J.; Bereiter, C. Knowledge building as a mediator of conflict in conceptual change. *Cogn. Instr.* **1997**, *15*, 1–40. [CrossRef]
14. Metz, K. Children's understanding of scientific inquiry: Their conceptualization of uncertainty in investigations of their own design. *Cogn. Instr.* **2004**, *22*, 219–290. [CrossRef]
15. Shayer, M.; Adey, P. *La Ciencia de Enseñar Ciencias: Desarrollo Cognoscitivo y Exigencias del Currículo [The Science of Teaching Science: Cognitive Development and Curriculum Demands]*; Narcea: Madrid, Spain, 1984.
16. Cook, C.; Goodman, N.D.; Schulz, L.E. Where science starts: Spontaneous experiments in preschoolers' exploratory play. *Cognition* **2011**, *120*, 341–349. [CrossRef] [PubMed]
17. Dejonckheere, P.J.N.; Wit, N.D.; Keere, K.V.D.; Vervaet, S. Exploring the classroom: Teaching science in early childhood. *Eur. J. Educ. Res.* **2016**, *5*, 149–164. [CrossRef]
18. Bullock, M.; Ziegler, A. Scientific reasoning: Developmental and individual differences. In *Individual Development from 3 to 12: Findings from the Munich Longitudinal Study*; Cambridge University Press: New York, NY, USA, 1999; Volume 3, pp. 38–54.
19. Schauble, L. The development of scientific reasoning in knowledge-rich contexts. *Dev. Psych.* **1996**, *32*, 102. [CrossRef]
20. Hsin, C.T.; Wu, H.K.; Tam, D.; Wei, M.E. Fostering young children's scientific practices in urban and Indigenous areas: An investigation of instructional strategies. *Int. J. Sci. Educ.* **2024**, 1–25. [CrossRef]
21. Borgerding, L.A.; Raven, S. Children's ideas about fossils and foundational concepts related to fossils. *Sci. Educ.* **2018**, *102*, 414–439. [CrossRef]
22. Moffett, L.; Moll, H.; FitzGibbon, L. Future planning in preschool children. *Dev. Psych.* **2018**, *54*, 866–874. [CrossRef]
23. Greenfield, D.B.; Jirout, J.; Dominguez, X.; Greenberg, A.; Maier, M.; Fuccillo, J. Science in the preschool classroom: A programmatic research agenda to improve science readiness. *Early Educ. Dev.* **2009**, *20*, 238–264. [CrossRef]
24. O'Connor, G.; Fragkiadaki, G.; Fleer, M.; Rai, P. Early Childhood Science Education from 0 to 6: A Literature Review. *Educ. Sci.* **2021**, *11*, 178. [CrossRef]
25. Kalogiannakis, M.; Nirgianaki, G.M.; Papadakis, S. Teaching magnetism to preschool children: The effectiveness of picture story reading. *Early Child. Educ. J.* **2018**, *46*, 535–546. [CrossRef]
26. Lindemann-Matthies, P. 'Loveable' mammals and 'lifeless' plants: How children's interest in common local organisms can be enhanced through observation of nature. *Int. J. Sci. Educ.* **2005**, *27*, 55–77. [CrossRef]
27. Dobson, C.; Postema, D. The amazing ecology of terrestrial isopods. *Sci. Child.* **2014**, *51*, 60–66. [CrossRef]
28. Torres, A.; Vitti, D. A kinder science fair. *Sci. Child.* **2007**, *45*, 21–25.
29. Ünver, A.O.; Arabacioğlu, S.; Okulu, H.Z. Experiencing inquiry with kindergarten: Science for kids. In *Education Research Highlights in Mathematics, Science and Technology*; Shelley, M., Kiray, S.A., Celic, I., Eds.; ISRES Publishing: Iowa City, USA, 2016; pp. 22–31.
30. Yin, R.K. *Case Study Research: Design and Methods*, 5th ed.; Sage Publications: Los Angeles, CA, USA, 2003.
31. Stake, R.E. Qualitative case Studies. In *Handbook of Qualitative Research*, 3rd ed.; Denzin, N.K., Lincoln, Y.S., Eds.; Sage Publications: Thousand Oaks, CA, USA, 2005; pp. 443–466.
32. Denzin, N.K.; Lincoln, Y.S. *Handbook of Qualitative Research*, 3rd ed.; Sage Publications: Thousand Oaks, CA, USA, 2005.
33. Lichtman, M.V. *Qualitative Research for the Social Sciences*; Sage Publications: Thousand Oaks, CA, USA, 2013.
34. Vygotsky, L. *Pensamiento y Lenguaje [Thinking and Language]*; Paidós Ibérica: Barcelona, Spain, 1995.
35. MacGavin, G.C. *Manual de Identificación de Insectos, Arañas y Otros Artrópodos Terrestres [Identification Manual of Insects, Spiders and Other Terrestrial Arthropods]*, 2nd ed.; Ediciones Omega: Barcelona, Spain, 2005.
36. Moreira, M.A. Investigación en educación en ciencias: Métodos cualitativos [Research in science education: Qualitative methods]. *Actas PIDEC* **2002**, *4*, 25–45.
37. Patton, M.Q. *Qualitative Research and Evaluation Methods: Integrating Theory and Practice*, 3rd ed.; Sage Publications: Thousand Oaks, CA, USA, 2002.
38. Calo, N.; García-Rodeja, I.; Sesto, V. Construyendo conceptos sobre electricidad en infantil mediante actividades de indagación [Constructing concepts about electricity in early childhood education through inquiry-based activities]. *Enseñ. Cienc.* **2021**, *39*, 223–240. [CrossRef]
39. Costa, T. Influência da Criação e Crítica de Analogias por Estudantes de Química do Ensino Médio na Promoção de Interações Argumentativas [Influence of Creating and Criticizing Analogies by High School Chemistry Students in Promoting Argumentative Interactions]. Ph.D. Thesis, Universidade Federal de Ouro Preto, Ouro Preto, Brazil, 2015.
40. Christidou, V.; Hatzinikita, V. Preschool children's explanations of plant growth and rain formation: A comparative analysis. *Res. Sci. Educ.* **2006**, *36*, 187–210. [CrossRef]

41. Piaget, J. *The Child's Conception of the World*; Routledge: London, UK, 1929.
42. Lorch, R.F.; Lorch, E.P.; Calderhead, W.J.; Dunlap, E.E.; Hodell, E.C.; Freer, B.D. Learning the control of variables strategy in higher and lower achieving classrooms: Contributions of explicit instruction and experimentation. *J. Educ. Psychol.* **2010**, *102*, 90–101. [CrossRef]
43. Piekny, J.; Maehler, C. Scientific reasoning in early and middle childhood: The development of domain-general evidence evaluation, experimentation, and hypothesis generation skills. *Br. J. Dev. Psychol.* **2013**, *31*, 153–179. [CrossRef]
44. Leach, J.; Driver, R.; Scott, P.; Wood-Robinson, V. *Progression in Understanding of Ecological Concepts by Pupils Aged 5 to 16*; The University of Leeds, Centre for Studies in Science and Mathematics Education: Leeds, UK, 1992.
45. Ibarra, S.C.; Escandell, J.C.; Wehrle, P.G.; Galindo, A.G.; Blake, A.M. Estudio del proceso de cambio conceptual y la construcción del modelo científico precursor de ser vivo en niños de pre-escolar [Study of the conceptual change process and the construction of a precursor scientific model of living beings in preschool age children]. *Enseñ. Cienc.* **2009**, 2556–2561.
46. Lazonder, A.W.; Egberink, A. Children's acquisition and use of the control-of-variables strategy: Effects of explicit and implicit instructional guidance. *Instr. Sci.* **2014**, *42*, 291–304. [CrossRef]

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Article

Preschool Class Children and Grade One Pupils' Questions about Molecules from a Digital Interactive Session at a Culture Center in Sweden

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Abstract: This study focuses on preschool class children and grade one pupils' questions about the natural sciences. The article presents the questions that preschool class children and grade one pupils asked via a chat function in connection with a digital interactive lesson about molecules arranged by a culture center in Sweden. The results of the thematic analysis are discussed in relation to their didactic implications for natural science teaching with young learners. The most relevant conclusions are that children drew from their own experiences when approaching molecules, they could generalize their experiences and apply them to other contexts, and they needed time to process the content and then ask questions. Therefore, the authors suggest the use of children's questions as a useful pedagogical tool for helping young children understand abstract concepts such as molecules. Furthermore, follow-up interviews with children are suggested as a means of mapping the origin of such questions.

Keywords: preschool class; chemistry; questions

1. Introduction

In Sweden, preschool education is provided by municipalities for children aged between one and five years old with an attendance rate of about 85% [1]. The Swedish preschool curriculum states as a goal that education at this level should "contribute to children developing an understanding . . . of simple chemical processes" [2] (p. 14–15).

Within compulsory school, there is a first year that is voluntary for children before they start grade one, known as preschool class or förskoleklass [1]. The Swedish preschool class curriculum states chemical phenomena as central content in the field of nature [3]. This study focuses on preschool class children (aged 6 years old) as well as grade one pupils (aged 7 years old) and the questions they posted about molecules.

Although preschool class is not compulsory, it helps prepare children for starting school. Such preparation is needed because of the differences between both stages. While play has a central role in the child's development during the preschool stage [2], school has more structured teaching that aims for the child to achieve the criteria for assessment in each subject in each course [3]. It is also known that if a child encounters a major difficulty during the transition period, this can have a negative impact on the child's learning and development [4]. Hence, supporting the transition from preschool to school is important [5].

From a cultural–historical perspective, play has a key role in the mental development of a child [6]. Children continually move between reality and imaginary situations in play, and this builds their capacity for thinking with concepts in science [7]. In the same way that children combine their prior experiences into a new concrete situation through play, science can also be conceptualized as an imaginative act [7]. For example, although children cannot see molecules, they can be introduced through a dramatization in which an actor is dressed up and behaves as a water molecule and moves at different speeds depending on temperature.

However, since the project took place in the middle of the COVID pandemic and followed the guidelines of the health authority that recommended avoiding physical contact with the participants [8], the only possible way to collect data was using digital technology. Therefore, this article can only present the questions that the children asked via a chat function connection with a digital interactive lesson about molecules arranged by a culture center in Sweden.

2. Previous Research

2.1. Children's Understanding of Molecules

Although molecules are central content in chemistry education, it has been shown that preschool children struggle to understand the submicroscopic level, which they cannot see [9]. How children understand such an abstract concept is an important prerequisite for teaching, guiding how teachers can support children in their emerging understanding of concepts. Åkerblom et al. [10] studied children's understanding of water and chemistry before and after participating in a drama activity focusing on the water molecule in a children's culture center. The study noted that the children showed different qualitative understandings of the water molecule. The children understand water in the following ways: through everyday understanding, their own experiences, and exploratory generalized understanding.

Within the category of everyday understanding, the children had difficulty expressing what water is. The children reasoned about the function of water as something we drink or how water manifests itself. What water consists of was not something the children reasoned about, nor did the children make any connections between water and the molecule concept.

As for the category of children who give an account of their own experiences, where most answers were found, the children pointed to the function and properties of water. Here, the children reasoned that water is something that surrounds us and that exists in different variations.

Finally, within the exploratory generalized understanding category, water is understood as something that can be studied, and the children's responses reflect refined ways of explaining the material world. Here, the children reasoned about the components of water and described, as in the previous category, water in different forms. What distinguishes the children's answers here is that they use scientific terms and show an understanding of their meaning, for example, about water's surface tension (when a child explains how water striders can float above the water's surface).

Overall, the children's understanding of water moved from being experienced sensuously to a more generalizing way of understanding.

Åkerblom and Pramling [11] analyzed how six-year-olds reasoned about their experiences and how they understood the content after participating in a drama activity focusing on molecules at a culture center. The starting point for the project was to see how the children manage the relationship between imagination (as if) and scientific content (as it is). Between these poles (the world "as if" and "as it is"), a tension field was described, which the children dealt with by reasoning in different ways: pretending to be molecules, using familiar phenomena such as similes to reason about things that are challenging, coordinating "as if", but also taking part in what the drama teacher imagines. In summary, Åkerblom and Pramling [11] found that the children used linguistic resources that they could master at the time, such as similes, to approach the scientific content, which would otherwise have required other linguistic resources to reason about. The researchers discuss the children's navigation between "as if" (the fantasy used in the pretend world they use in their play and stories) and "which it is" (the real world they perceive through their senses in reality) in the same way scientific phenomena that children experience through their senses need to be described in a manner so that children can actually understand them. Since most of the articles are in Swedish, three references from English-speaking publications that have addressed similar topics can be found in the following references: [12–14].

The above results show that molecules as content can be understood in qualitatively different ways by younger children. After participating in a drama activity, children approach this scientific content by reasoning with the help of different linguistic expressions, such as similes, which take place in the tension field between fantasy and reality. Therefore, children's linguistic expressions in different forms can act as a kind of guide for how they approach or understand content. Children's questions can be considered a form of such linguistic expressions and, regardless of the "teaching form" (whether it is a digital lesson or a drama activity), constitute a prerequisite for teaching. It is also relevant at a time when teaching takes place through digital forms to investigate how children perceive different content and what questions they ask about the content because there may be differences compared to learning taking place without a digital interface.

2.2. Children's Questions as a Starting Point for Teaching

The questions that teachers ask in science teaching to develop children's understanding have been the subject of research [15,16]. Conversely, children's questions, as a starting point for science teaching, can be significant for children's meaning-making and understanding of the content. Within the Swedish preschool context, Thulin [17] investigated what kind of questions children (3–5 years old) ask during an activity as part of themed work about what soil is and how soil is created. Of the over 200 questions asked, the study shows that children most commonly ask the following questions:

- Questions related to the content (173 questions: about doing something with the content, about knowing something about the content, about understanding something about the content, about relating the content to their own or common experience, about being involved in the content).
- Questions related to tools (22 questions: about getting to use tools, about understanding how to use tools, about sharing tools).
- Questions not related to the content (11 questions).

Furthermore, the children's questions increased the longer the theme work went on, which can be understood as the children "...need to be introduced to a field of knowledge, be able to relate experiences before they can ask questions about it" [17] (p. 36). In summary, Morais et al. [14] shows that most of the children's questions relate to content (knowing something about the content) and processes (doing something about the content). Children's interest in learning about content is of didactic importance for various reasons. This has consequences for teachers' didactic choices both before and during science teaching. It is also significant from the children's perspective to know about the children's (pre)understanding of the content.

In another project with a focus on ecology, Halvars [18] investigated how preschool children ask questions and create meaning in encounters with trees. The project, which used an exploratory working method, lasted for a school year, in which 28 children and three preschool teachers participated. In encounters with trees, children make connections to their own lives (for example, the family circle), their own bodies (based on form and function), the trees' internal and external systems, living conditions for animals that are around the trees, and how the trees communicate. This study also makes visible content-specific aspects, where the children mostly relate to the content based on their own experiences.

Hansson et al. [19] compiled children's questions and situations as potential science learning situations. This was carried out within the framework of the "preschool upgrade", which includes qualifying courses for teachers in many subjects and school forms such as science, mathematics, technology, or reading techniques, as well as special teacher training. In this case, the participating preschool teachers themselves identified situations and children's questions. A total of 295 questions with chemistry and/or physics content were found. Of the 295 questions, 107 questions/situations had potential chemistry content, and 209 had potential physics content. In terms of chemistry content, most questions/situations dealt with various substance and material properties or phase transformations. There were also questions/situations about chemical reactions.

Overall, the studies above point to children's questions as a starting point for science teaching. Children's questions can be seen here as linguistic expressions of children's perspectives, which science content interests them or how they understand and approach science content. The children's questions, after being interpreted, can function as a didactic tool for teachers' planning and how they can challenge children through teaching.

The purpose of this article is to study preschool class children and grade one pupils' questions during a digital interactive chemistry lesson and to categorize them to later discuss the didactic implications for science teaching at this stage.

3. Method

3.1. Data Collection

In May 2020, during the ongoing COVID-19 pandemic, a culture center located in a major Swedish city broadcasted an interactive lesson digitally via its website. The content of the lesson consisted of the following elements:

(a) A transmission of a pre-recorded dramatization on the theme of molecules (gestalting, a molecular dance, and an experiment). Drama educators from the cultural center acted in the dramatization, where they pretended to be solid, fluid, and gaseous water molecules and moved at different speeds as the temperature increased [10].
(b) A chat function where the participating preschool classes/schools could ask questions. The chat function ran throughout the entire broadcast.
(c) A review where chemists from a technical university answered the children's questions that had been asked in the chat.

The natural science content for the lesson was molecules, and previously, the lesson had been given on location (IRL) for interested classes in collaboration between a cultural center and a technical university. The interactive lesson given on site is usually offered for preschool children and for grade one pupils.

What makes this intervention unique in comparison to other instructional films about molecules is its multimodal format. Children are first introduced to molecules through a dramatization in which a person acts as a water molecule. Then, the children are asked to represent a water molecule in a solid, liquid, and gaseous state, moving at different speeds according to the temperature. Finally, the children observe through an experiment how a sugar cube melts faster in hot water than in cold water, and the same happens with food coloring.

Around 515 classes were registered for the lesson, consisting of 13,499 children and 1321 teachers from preschool classes and grade one classes from different parts of Sweden, amounting to a total of 14,770 participants. In connection with the lesson, questions could be asked in the chat. Since the children could not type the questions themselves, they raised their hands, and their class teacher typed the questions they asked one at a time in the online chat. The questions written in the chat constitute the total collected material for the study, which unfortunately shows that not all the classes asked questions. The questions formulated in Swedish were translated into English by the second author and then checked by the first and third authors.

In this study, unfortunately, there are no data about whether the questions arose during the lesson and/or as part of the science teaching in the participating classes. The same applies to whether the children formulated and/or wrote the questions themselves in the chat or with the help of the teachers. The recorded questions can therefore be seen as expressions of what the children (group) wanted to know more about regarding molecules in connection with the digital lesson. Thus, the questions asked are an "active" document that represents the children's existing perceptions and thoughts about molecules. Asking questions can be seen as part of the children's sense-making about the content of "molecules".

3.2. Ethical Considerations

The Swedish Research Council's [20] good research practice guidelines were followed. The participants were informed that the activity was connected to research purposes, and by signing up for the virtual session, they consented to participate in the study. The identities of the students formulating the questions have been kept anonymous since the data collected did not provide names at all. The objective of the research was to build knowledge about natural science didactics within the field of chemistry.

3.3. Data Analysis

In order to understand the meaning of the children's questions and what it is the children wanted to know more about regarding molecules, the children's questions need to be interpreted. A thematic analysis was used as an analysis method. Säljö [21] wrote that this method is suitable for distinguishing and analyzing different patterns or themes. The different themes must capture something valuable in relation to theory and the research question/s, and this method can be used based on different theoretical frameworks.

As the children's questions were asked in a digital interactive context, these are discussed in relation to a sociocultural perspective [22], which regards learning as social, where different participants interact with others in a specific context. Through interaction with others, for example, knowledge and ways of thinking are shared. Knowledge of molecules is potentially increased by taking part in the content of the digital lesson. The digital lesson constitutes the specific context in which the participants (children, teachers, researchers, drama pedagogues, the content) communicate through the chat and the questions that are asked.

Artifacts are cultural products that humans have created and are important tools for interaction. Through these, knowledge is transferred or mediated to the participants in a specific context. Artifacts can, for example, be linguistic, mental, or digital [22]. The children's questions can be seen here as linguistic artifacts and the chat as a digital artifact. The concept of "molecules" is a mental artefact that is significant for teaching chemistry. These artifacts enable the participants to interact and knowledge to be (re)created in a specific context. Through the content of the digital lesson, knowledge about molecules was mediated, and the questions asked in the chat mediated knowledge about the children's understanding of molecules.

4. Results

The questions were recorded in the order that they appeared in the chat. After the broadcast, an excerpt was also provided with all the questions asked in the chat by the person in charge of the cultural center. In this way, a double check took place so that no questions would be overlooked. In the chat, the name of the school and/or the teacher and the question itself appeared. The school/teacher's name was initially included to ensure that no questions were missed, but was then deleted and does not appear in the results presented. If the same question was asked several times, it was only included once, generating 53 different questions.

Afterwards, each question was summarized in terms of content. Upon repeated reading, questions dealing with similar content could eventually be sorted under the same subtheme. The subthemes were compared with each other and arranged according to different content themes. Finally, six different themes crystallized: *the origin of molecules*, *molecules and their properties*, *molecules as constituents*, *reactions and interactions of molecules*, *molecules and science,* and *other questions*. In the next step, these subthemes were sorted.

4.1. The Origin of Molecules

The theme summarised in Table 1 includes a small number of questions. These questions can be interpreted as having an ontological and causal nature, where children want to know more about the background of molecules and what caused their creation. Based on these questions, we conclude that the children relate to molecules as part of the universe and try to understand their place in the universe historically (from the beginning, where do they come from) but also what causes their emergence (how do they appear, how are they born, how are they created). Most questions begin with the question word how.

Table 1. The origin of molecules' theme, subtheme, and examples.

Theme	The Origin of Molecules
Subtheme and examples	Background and becoming - How are molecules born? - Where do molecules actually come from? From the beginning? - How did water molecules appear? - How long have molecules been around? - How are molecules created?

4.2. Molecules and Their Properties

Within the theme on Table 2 are the second most frequently asked questions. These questions focus on the classification of what molecules are based on, as well as what properties molecules are assumed to have. The questions indicate that the children want to understand the nature of molecules. The questions asked about their properties concerned their weight, size, appearance, and structure. They can be summarized as having a comparative and measurable character, and these too usually begin with how to obtain answers to how molecules are made up; for example, questions beginning with "How much weighs..." and "How big..." were asked. These questions can be understood as the children relating to molecules through ideas and experiences connected to their own world, for example, whether they eat or get sick. In summary, the questions within this theme are about arranging, defining, comparing, and determining the nature of molecules based on their different properties; "are they alive or are they a thing?" and "are they red...?" are some of the questions asked.

Table 2. Molecules and their properties' theme, subthemes, and examples.

Theme	Molecules and Their Properties
Subthemes and examples	Taxonomy/classification - What are molecules? Are they alive or are they a thing? - Are there sickness molecules? Weight - How much does a molecule weigh? - How much does a sugar molecule weigh? Size - How big can a molecule be? - How big is a molecule? Are there different sizes? - How big is a glass molecule? Appearance - How do air molecules look like? - Are there other-colored molecules? - Are water molecules red for real? Structure - Can we take a molecule? - Why do molecules not have a brain? - How can water molecules go up and down? Vulnerability - Can molecules be sick? Nutrition - Do molecules eat?

4.3. Molecules as Constituents

The majority of the children's questions were within this theme on Table 3. The questions concern the relationship between molecules and the rest of the world and other things. The questions were about where molecules can be found, whether they are constituents of different things, and to what extent ("how many molecules. . .?") they can be found in different things.

Table 3. Molecules as constituents' theme, subthemes, and examples.

Theme	**Molecules as Constituents**
Subthemes and examples	Constituents - Are there water molecules in everything? - Are there molecules in the molecules? - What is a sugar molecule made of? - Are there molecules in all the liquids? Object - Does light consist of molecules? - Are there molecules in pencils? - Are there molecules in computers? - Are there molecules in paper? - Are there molecules in glass? - Is lava a molecule? Living things - Do flowers also have molecules? - Are insects made of molecules? Which ones? - Are bacteria made of molecules? Body - Does sweat have water molecules? - Does COVID have molecules? Space - Are the molecules all over the universe? - Are there molecules in space? - Are there molecules in black holes? - Has the vacuum no molecules? Physical phenomenon - Does energy consist of molecules? - Does electricity consist of molecules? - Does light consist of molecules? Quantity - How many molecules are there in a sugar cube? - How many molecules are there in the body? - How many molecules are there? - How many water molecules are there in the world?

The question "Does light consist of molecules?" is represented under two different categories, as it is difficult to know which "kind" of light the children were referring to (whether they meant a candle or, for example, sunlight).

4.4. Reactions and Interactions of Molecules

The theme on Table 4 points to the children's curiosity about what happens when molecules come into contact with other substances or are even in different states. Within this theme, the children can be interpreted as having an ambiguous idea of molecules. In part, questions such as "What does it look like when the water molecules are mixed?" indicate an understanding that molecules interact with their environment and come into contact with other substances. In this sense, molecules are assigned an active role. In part, other questions may point to the passivity of molecules when they are exposed to various actions. The following example can illustrate this: "What happens to the water molecule when we drink the water?" refers to an external influence where someone else's actions will affect the state of molecules.

Table 4. Reactions and interactions of molecules' theme, subtheme, and examples.

Theme	**Reactions and Interactions of Molecules**
Subtheme and examples	Contact with other subjects - What happens with water molecules when we drink water? - What happens to water molecules when we finish drinking water? - How does it look when we mix water molecules with sugar?

4.5. Molecules and Science

A few questions had a scientific focus and concerned how we acquire knowledge about the natural sciences, as summarised on Table 5. One question concerns how our knowledge of molecules can be guaranteed and has an epistemological character. The other question is more general and refers to one child wondering about the science of chemistry.

Table 5. Molecules and science's theme and examples.

Theme	**Molecules and Science**
Examples	- How do we know that there are molecules? - How does chemistry work?

4.6. Other Questions

The questions within the theme on Table 6 differ from the others, as they are of a practical nature and refer to the execution of the digital lesson. In summary, the content of the questions has an indirect relationship or a nonexistent connection to molecules. One of the questions concerns the props, for example, "the green" that is in front of the acting drama teachers, and the answer can be seen as important for understanding what happens during the lesson. Another explanation could also be pure curiosity about what "the green" is. The latter question can also be interpreted as the children knowing that there is usually a real audience during lessons in the cultural center. The children may thus seem to relate to previous experiences; possibly they have visited the culture center and seen various performances that are now part of the digital lesson.

Table 6. Other question's theme and examples.

Theme	**Other Questions**
Examples	- What is the green thing in front of you? - Are there students with you now?

5. Discussion

With reference to the purpose of the study, the children's questions show that molecules are a subject that interests the children, as most of the questions were about molecules. In previous studies, there have been similar results [17]. Both the themes and subthemes point to variation in the content of the questions. The questions illustrate different aspects of molecules; some of the questions are about understanding what a molecule is in order to use molecules to understand material things or phenomena. Only a few questions have a general science focus or do not relate to the lesson's content.

Like previous studies, the children started with their own experiences [10,18] when they wanted to know more about molecules. Here, this relates to the children asking questions about molecules in relation to things they recognize (pencils, computers, light, sugar, glass) or to situations that they themselves have been involved in, for example, being sick or eating. Properties have also been shown to be a starting point when children reason about water molecules [10] or ask questions about chemistry content [19]. Also, in this study, the children asked questions about the properties of molecules, such as their appearance, weight, and size. The questions about properties seem to be a way for the children to classify what molecules are and relate them to other things they know. The properties function as a comparison between different things and phenomena. Furthermore, connections to one's own body [18] can also be seen, as some of the questions contained concepts such as the brain, sweat, coronavirus, bacteria, and sickness. In summary, the various connections (experiences, properties, the body) to molecules can act as a way for children to create connections between what they know and a possible new area to learn about. Asking questions thus functions as a tool to explain one's world.

Some of the children's questions specifically concerned the water molecule, while the rest were about other kinds of molecules or questions about molecules in general. The fact that the water molecule was depicted in the digital lesson could explain why certain questions concerned the water molecule. On the other hand, the questions that did not focus on water molecules in particular show that children can generalize their experiences and apply them in other contexts. In terms of teaching, this means that the water molecule is an excellent subject for challenging children's thoughts about what molecules are and how they form building blocks for the creation of various known things, materials, etc.

The children's questions are also of didactic value, as they show what interests the children and how they approach chemistry content. The different themes and subthemes summarize aspects of content that teachers can build their teaching upon, for example, when introducing different content. What the children ask for can also be a way to take part in the children's pre-understanding and conceptual understanding, as well as possible misconceptions. These are all equally important aspects of work dealing with natural science.

From a sociocultural perspective [22], the children's expression of what they want to know more about molecules can be understood as the children being knowledgeable participants in a scientific context. Their thoughts and questions are valuable building blocks in the creation of knowledge about important content regarding natural science. Asking questions is thus a linguistic tool for interacting with others about important cultural content in natural science. The chat functions as a receiver in the interactive context where knowledge is created between the different participants: on the one hand, the children (and teachers) who ask the questions, and on the other, the chemists who answer the children's questions. The chat enables interaction so that different ways of thinking about molecules are shared. As several different classes participated in the interactive digital lesson, this knowledge was spread between schools. The interactive lesson as a whole (dramatization, chat function with questions, explanations) constitutes a digital artifact that enables interaction where knowledge is distributed between different participants. Knowledge is thus not "static", but is created and re-created through questions and shared by many different participants (each within their own context).

Molecules are an abstract subject. This digital lesson can be a way of introducing and/or illustrating this abstract content through multimodal forms, corroborating how visual computer animations have previously been shown to help [23]. The digital lesson itself can be experienced as abstract because much of its content (dramatization, experiments) is pre-recorded. If the lesson had been given on site in the cultural center, the children could have "hands-on" experiences in, for example, the molecular dance (the movements of molecules at different temperatures). Instead, the children could interpret the content of the lesson digitally. Possibly, the children would have asked different questions if they had been there after acting as the molecules themselves or experimenting. At the same time, the chat, as a digital forum, enabled the various participants to gain access to other people's questions and ways of thinking.

In addition, the questions asked in the chat were answered orally (the vast majority of questions) and in writing (all the questions). That way, all classes could take part in the content. Even though the chat function was available throughout the broadcast, it still represents a limited amount of time to formulate and ask questions while taking part in the lesson. The children may have needed time to process the content and then ask questions. Research shows that children ask more questions the longer you work with an area [17]. Conversely, classes that have previously worked with this chemistry content may find it easier to formulate questions in the context of the interactive lesson. This generates new questions, which puts the focus on teaching: what understanding do the children have when they are to take part in digital "lessons", or in what way are the children's questions developed based on digital lessons? Based on a sociocultural view of learning, it is of interest to follow some classes more closely to study their interaction in the classroom and how questions are created during a digital interactive lesson.

Limitations of the Study

Although access to interactions between the teacher and the children is not possible because of the circumstances of the digital chat, which only allowed access to the online text, the fact that a high number of participants posted questions ensures that the data have a high level of reliability.

Unfortunately, no follow-up interviews with the children and their teachers were carried out due to time constraints. Nevertheless, access to these data would certainly enrich the analysis.

6. Conclusions

The results of the study can be summarized in the following three points: First of all, the children drew from their own experiences when approaching molecules. Secondly, the children were able to generalize their experiences and apply them to other contexts. Thirdly, the children needed time to process the content and then ask questions.

Therefore, the use of children's questions as a strategy for supporting young students' understanding of scientific concepts is suggested as a useful pedagogical tool. As pointed out by [24], it is not enough that children participate in science activities; their teacher needs to engage them in discussion and problem-solving situations to find answers to the questions posed that are meaningful for them.

A suggestion for future lines of research could consist of follow-up interviews with the children participating in the activity in order to expand on the children's explanations about their questions and try to understand where they come from.

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References

1. Swedish Institute. The Swedish School System. 2023. Available online: https://sweden.se/life/society/the-swedish-school-system (accessed on 15 June 2023).
2. Skolverket. *Curriculum for the Preschool Lpfö18*; Skolverket: Stockholm, Sweden, 2018.
3. Skolverket. *Läroplan för Grundskolan, Förskoleklassen och Fritidshemmet Lgr22*; Skolverket: Stockholm, Sweden, 2022.
4. Ma, J.; Hammer, M.; Veresov, N. Cultural-historical study of crises in child role adjustment during transition to school within a bi-cultural context. *Early Child Dev. Care* **2022**, *192*, 1243–1256. [CrossRef]
5. Hedegaard, M.; Fleer, M. *Play, Learning and Children's Development: Everyday Life in Families and Transition to School*; Cambridge University Press: Cambridge, UK, 2013.
6. Vygotsky, L.S. Play and its role in the mental development of the child. *Int. Res. Early Child. Educ.* **2016**, *7*, 3–25. [CrossRef]
7. Fleer, M. Imagination and its contributions to learning in science. In *A Cultural-Historical Study of Children Learning Science: Foregrounding Affective Imagination in Play-Based Settings*; Fleer, M., Pramling, N., Eds.; Springer: Berlin/Heidelberg, Germany, 2015; pp. 39–57.
8. Public Health Agency of Sweden. COVID-19. 2023. Available online: https://www.folkhalsomyndigheten.se/the-public-health-agency-of-sweden/communicable-disease-control/covid-19/ (accessed on 17 June 2023).
9. Vidal Carulla, C. *Children's Emergent Chemistry in the Preschool*; Linnaeus University Press: Kalmar, Sweden, 2020.
10. Åkerblom, A.; Součková, D.; Pramling, N. Preschool children's conceptions of water, molecule, and chemistry before and after participating in a playfully dramatized early childhood education activity. *Cult. Stud. Sci. Educ.* **2019**, *14*, 879–895. [CrossRef]
11. Åkerblom, A.; Pramling, N. Dramatisering i spänningsfältet mellan som om och som är och sexåringars meningsskapande av kemiska begrepp och processer. *Educ. Vetenskapliga Skr.* **2019**, 58–72. [CrossRef]
12. Fridberg, M.; Jonsson, A.; Redfors, A.; Thulin, S. Teaching chemistry and physics in preschool: A matter of establishing intersubjectivity. *Int. J. Sci. Educ.* **2019**, *41*, 2542–2556. [CrossRef]
13. Gelir, I. Preschool children learn physics, biology, chemistry and forensic science knowledge with integrated teaching approaches. *Int. J. Early Years Educ.* **2022**, *30*, 891–905. [CrossRef]
14. Morais, C.; Araújo, J.L.; Saúde, I. Awakening to chemistry through storytelling and practical activities: Middle school students interacting with pre-school children. *Chem. Educ. Res. Pract.* **2019**, *20*, 302–315. [CrossRef]
15. Lee, Y.; Kinzie, M.B. Teacher question and student response with regard to cognition and language use. *Instr. Sci. Int. J. Learn. Sci.* **2012**, *40*, 857–874. [CrossRef]
16. Furman, M.; Luzuriaga, M.; Taylor, I.; Jarvis, D.; Dominguez Prost, E.; Podestá, M.E. The use of questions in early years science: A case study in Argentine preschools. *Int. J. Early Years Educ.* **2019**, *27*, 271–286. [CrossRef]
17. Thulin, S. Barns frågor under en naturvetenskaplig aktivitet i förskolan. *Nordisk Barnehageforskning* **2010**, *3*, 27–40. [CrossRef]
18. Halvars, B. Barns frågor under en utforskande process kring träd. *Nord. Nord. Stud. Sci. Educ.* **2021**, *17*, 4–19. [CrossRef]
19. Hansson, L.; Löfgren, L.; Pendrill, A. Att utgå från frågor och situationer i förskolans vardag: Vilket naturvetenskapligt innehåll kan det leda till? Starting from questions and everyday situations in preschool: What kind of science content could that lead to? *NorDiNa Nord. Stud. Sci. Educ.* **2014**, *10*, 77–89. [CrossRef]
20. Swedish Research Council. God Forskningsskeds. 2017. Available online: https://www.vr.se/analys/rapporter/vara-rapporter/2017-08-29-god-forskningssed.html (accessed on 19 June 2023).
21. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [CrossRef]
22. Säljö, R. *Lärande i Praktiken. Ett Sociokulturellt Perspektiv*; Studentlitteratur: Lund, Sweden, 2013.
23. Adbo, K.; Vidal Carulla, C. Learning about science in preschool: Play-based activities to support children's understanding of chemistry concepts. *Int. J. Early Child.* **2020**, *52*, 17–35. [CrossRef]
24. Fleer, M.; Gomes, J.; March, S. Science learning affordances in preschool environments. *Australasian Journal of Early Childhood* **2014**, *39*, 38–48. [CrossRef]

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Article

Symbolic Representation of Young Children in Science: Insights into Preschoolers' Drawings of Change of State of Matter

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Abstract: Research in early childhood education acknowledges the multimodal nature of learning, and the need to equip young learners with the abilities to encounter future communication and learning challenges is imperative. Drawing can play a crucial role in children's learning in general and contribute to science learning in particular. In this paper, we study the drawings that young children (aged 4–6) produce during a teaching intervention about the change of state of matter. The research adopts a sociocultural perspective, considering drawing as a mediating tool to support children's meaning-making and learning process. The objective is to understand better the type of drawing situations that can be proposed to young children in science and the scaffold these drawing tasks might provide to support meaning-making in science. Results show that children use iconic as well as symbolic modes of representation depending on the situation and that the resources available can have an impact on how children use different symbols.

Keywords: early childhood science; drawings; symbolic representation; iconic representation; young children's ideas; change of state

1. Introduction

Considering learning both a meaning-making and a participatory process at school and in other contexts of children's everyday life, emphasis is placed on the study of the various modes or «languages» that can support this learning process. Drawing can be considered one such language, which is why it is often a popular practice in early childhood education (ECE) [1]. Drawing is an activity that children are introduced to at a very early age. According to Hope [2] (p. 3) «the word 'drawing' is one of those action words which can describe both a product and a process. 'To draw' is to purposefully make a mark; a 'drawing' is the result of that mark-making». Research studies [3,4] have shown that drawing is more complex than mere mark-making, as representational drawing implies that children have realized the concept that pictures can be symbols that stand for something. «In contrast to the rules of phonetics, drawing is open-ended and offers children a flexible means of representation and communication» [5] (p. 182). Children use drawing to represent knowledge, experience, and emotions to create a meaningful whole that combines diverse elements of their experience. To accomplish this, they have to select, interpret, and reform these elements [5]. Drawing can be used actively and dynamically to support, develop, and expand thinking and learning. The creation of improvised symbols and their adaptation and use in more complex graphic representations in the classroom reflect a dynamic process through which children become aware of their representational abilities [6].

Drawing is also used as a means for eliciting children's ideas in the field of Early Science Education [7,8]. Research on how children explore concepts and phenomena from the natural world indicates that children document their ideas and experiences by drawing to become involved in scientific thinking. Drawing is usually used during classroom inquiries, where children may draw to record data they have encountered in books, on the internet, and by observing the natural environment [5,9,10].

Drawing can provide an insight into children's ideas, can develop representational and symbolic abilities, and can extend children's thinking; by achieving this, it can help children build a foundation of visual literacy [7,11]. Having in mind that educators need to equip young learners with the necessary abilities to encounter learning challenges, we suggest that drawing, having the characteristics of a visual language, can serve as a mediating tool for knowledge construction and, in particular, the development of symbolic representation in science. Science often involves the study of non-observable entities; therefore the use of symbols and the development of representational competence can enhance children's scientific learning.

Within this context, this paper addresses the following research questions:

- What mode of representations are used by children to communicate meaning in different drawings during a science activity?
- Which symbols do children create through their drawings when different semiotic resources are made available?

The objective is to understand better the type of drawing situations that can be proposed to young children in science and the scaffold these drawing tasks might provide to support meaning-making in science.

2. Theoretical Framework

2.1. Drawing and Meaning-Making

Within a sociocultural framework, knowledge is not considered to be acquired passively by children. Instead, children are considered as active agents, and learning is seen as occurring through children's participation in various activities in the context of social interactions and cultural tools, which serve as mediating components that transform knowledge and create meanings [12,13]. Drawing is an ordinary activity for preschool children, and they use it extensively at school, in play, and in other daily activities at home [5]. Documenting their experiences and understandings through visual representations, including drawings and photos, is a common practice in ECE, which supports young children's learning [14]. Furthermore, drawing activity is considered important for the development of children's symbolic competences and for leading "to the further development of abstract thinking, imagination, and logic reasoning" [15] (p. 151). Wood and Hall [16] (p. 270) assert that

> *drawing is much more than a pre-writing skill, or a developmental transition from 'drawing things to drawing speech'. The focus is on understanding the more complex purposes that drawing fulfils for young children, as an intrinsically valuable form of abstraction and communication, as a social practice, and as a symbolic means of bridging home and school contexts.*

van Oers [17] used the term semiotic activity to describe the process of meaning-making, which is carried out through symbolic systems highlighting the interrelationship between iconic and symbolic thinking. He pointed out that "schematic representations (like drawings, for instance) are often used as a starting point for the semiotic activity of young children, as they can be used as meaningful objects of conversation" [17] (p. 239). This is shared by Brooks [18], who argues that drawing includes a child's efforts at abstraction; reflecting on their own representations usually allows a child to elaborate their ideas further.

Much of the research in the field of sociocultural approaches looks at children's drawing as a symbolic activity that supports learning and therefore needs to be recognized in early education [5,18–20]. Supporting the social genesis of drawing activity, as a learning process that is not accidental but occurs in the context of actions that are meaningful to the child, Longobardi et al. [21] (p. 1) argue that "the emergence of mental representations and, thus, the ability to use a signifier to evoke meaning, would not seem to be compatible with an activity that stimulates the pleasure of mere exercise". Starting from scribbles, they argue that children's drawings increase in complexity and that there are "important parallel transformations between the development of drawing skills and language development. Thus, we can witness a reorganisation of both the child's language system, which allows for better communication effectiveness, and graphical system, with the appearance of figurative schemes" [21] (p. 7).

By acknowledging drawing as a language (meaning, a communication and thinking tool), it becomes a fundamental mediating system for knowledge construction. Learning occurs in the context of actions that are meaningful to the child; no activity is meaningful in itself but only when linked to relationships with others or tools [13]. Children's drawing activity, when perceived as a social practice, can help educators and researchers realize the way children move from accidentally making marks on paper to conscious semiotic actions [22]. Moreover, when there is an appropriate response to children's drawings, e.g., appreciation, recognition, or reward from teachers, classmates, or parents, children receive a very important message: that they have achieved a representation that is acceptable and understood by those around them [22].

2.2. Drawing and Pictorial Representation of Science

We have been highlighting the interest shared by many researchers to consider the potential of drawings as a tool for constructing and sharing meaning for young children [1,3,5]. Fewer researchers have been interested in drawings related to a specific content knowledge [8,23]. There are arguments supporting the contribution of drawing to science learning; Areljung et al. [24] (p. 2) pointed out that drawing may support children's conceptual learning in science by making their understanding explicit, can serve as evidence or indicate their conceptual knowledge and progress in science, and can facilitate communication of knowledge in science as well as the development of visual literacy in science. Drawings are used by children as a tool to understand and represent important elements of their knowledge and experiences. In addition, drawing contributes to document-specific science content, «spanning from small organisms to astronomical objects, as well as to visualise 'the invisible"» [24] (p. 1). Areljung et al. [7] used the term "emergent disciplinary drawing" to describe children's attempts to draw using science-specific forms of visual language (p. 924). In their research, they used the following categories to describe how children represent science content: theory (general aspects from a scientific point of view), context (content is placed in a setting), event (movement or processes), art, person, and culture (pp. 913–14). Monteira et al. [20] also used coding categories for the analysis of children's drawings: modality (scientific and non-scientific), point of view (interactive meaning), salience, information value (position in the center or sides), and framing (compositional meaning).

Regardless of the various categorizations that can be introduced by studying the content of children's drawings in science, a basic distinction concerns the symbolic and iconic nature of pictorial representations in science, depending on how abstract they are or how realistic they are. Schnotz [25] introduces the categories of descriptive or depictive representations of science. Descriptive representations do not intend to have a specific structural similarity with the content matter or the object represented; they consist of symbols describing an object. In contrast, depictive representations show similarities with the object they represent. Another way of considering drawings in science is the categories of Niegemann et al., cited by Opfermann et al. [26], which distinguish realistic pictures, analogy pictures (e.g., a circuit of cars traveling bumper-to-bumper to depict an electrical circuit) and logical pictures (such as diagrams or graphs). Realistic pictures refer to the category of depictive drawings. The advantage of such visual representations is to present concrete knowledge; however, the realism of the drawing can also become an obstacle when too many details of a complex object can distract learners or stress cognitive capacities. Analogy pictures (depicting content with an analogy) and logical pictures (depicting content schematically) use symbolic representations and are more suitable to represent abstract concepts. However, this also requires a certain familiarity of the learner with the conventions of how to understand such representations. In a classic semiotic perspective, Peirce [27] distinguishes symbols and icons. Icons refer to images that represent reality by capturing the distinctive features of a phenomena and, as such, serve as prototypes of that kind of phenomena. DeLoache [28] proposes the working definition of a symbol as "something that someone intends to represent something other than itself" (p. 66). Symbols are arbitrary but hold a conventional relation to what they refer to. As a result, the recognition of a symbol is linked to the use that is made in a given context in order to refer to a specific concept. Science teaching is specific in that sense because it requires navigating between observable experimental situations and abstract entities that are not perceived directly [29]. Representing science therefore requires navigation between iconic and symbolic representations.

When children learn science, they have to learn to explain a world that they can see, touch, or feel with models using abstract concepts [29]. When children draw, they produce and compose a variety of signs to generate the meaning they intend. To do this, they need to respond to design challenges, such as representing three-dimensional objects or projections in a plane surface [30], movements, and modifications; thus, they use different symbols or make substantial abstractions [31]. As such, when children draw in science, they have to learn how to interpret and produce various signs that represent the abstract concepts of science and navigate between descriptive and depictive representations of science. Engaging in drawing activities in science can help children to gain a better understanding of science [4]. However, with our focus on science in early childhood settings within a socio-cultural perspective, we move away from the question of science drawing according to a normative perspective; the objective is to ensure that children acquire the rules of formal scientific representations. This is not intended to "score" as incorrect and correct the representations of young children in science, nor is it intended to indicate which representations are "valid" in terms of detail, accuracy, and correct sequence. Our objective is rather to study how young children define their own rules of representation for meaning-making in science and how these representations hold the potential for the teacher to develop a first disciplinary affordance in science. In this perspective, examining children's drawing activity as a meaning-making process, i.e., as a symbolic activity, we use the concept of change of state of matter to present the continuum that exists between iconic and symbolic representation in order to facilitate teachers' use of children's drawings as a learning tool of science.

3. Context of the Research: Drawing and Young Children's Understanding of the Change of State of Matter

The present research was developed in the context of teaching young children about the concept of change of state of matter (melting and freezing). It is based on the ideas supported by many researchers in early science education [32–34] that young children can observe and describe phenomena and are capable of developing initial knowledge about scientific phenomena. Therefore, early science activities lay the foundation for more complex ways of thinking. The concepts of melting and freezing are interesting phenomena to study because they are often part of children's everyday experiences and easy to experiment with. At the same time, they are phenomena that require bringing together concepts of time, temperature, transformation, conservation of matter, and reversibility and are therefore complex to comprehend. Few studies address this issue with preschoolers [35–37].

Rahayu and Tytler [38] refer to the concept of substance and the idea of its transformation and suggest a focus on changes of state in order to teach about materials in early primary years. Young children may be familiar with the melting process, e.g., acknowledging the melting of ice cubes in liquids, and therefore assume that melting always produces water; however, it is not possible to generalize the process for all materials [39]. Sensory experience plays an important role in the change of state phenomena, without taking into account the conditions under which the change of state takes place [37,40]. Children also usually use the terms hot and warm as synonymous and therefore do not differentiate between temperature levels. As well, they often confuse the concepts temperature and heat [41,42]. In addition, they attribute thermal properties to the materials from which the objects are made; they do not easily comprehend the concept of heat equilibrium [37], and understanding the use of the thermometer appears to be quite challenging [43]. Despite the differences among specific topics and methodological choices of the above studies, they all point to the fact that children can develop an interest in the issues from an early age.

However, we want to bring forward the specificities related to drawing objects that are melting. First of all, this requires that the concept of matter should be considered independently of the object [38]. Thus, for young children, the change of state raises the question of the conservation of matter and consequently how the object changes with time. Moreover, it is difficult for children to recognize the link between the state of a material and its temperature as well as the idea that objects placed in a given environment will all have the same temperature as that environment after a certain time [42]. Generally speaking, representing a change of state, and in our case, the phenomenon of melting, raises several questions. The first concerns the method of representing the transition from a solid state (an object with its own shape) to a liquid state, in which the initial object is no longer recognizable and no longer has its own shape. The second concerns a simultaneous representation of a reduction of matter in the solid state and an increase in matter in the liquid state. The third question is related to the notion of temporality and concerns the moment or moments to be represented in an initial state, multiple intermediate states, and a final state. Finally, the question of representing the change in temperature that comes with the change of state is also difficult to consider for children that are not familiar with formal temperature measurements using thermometers. It is all of these parameters that we are interested in regarding the children's drawings.

4. Methodology

4.1. Research Design

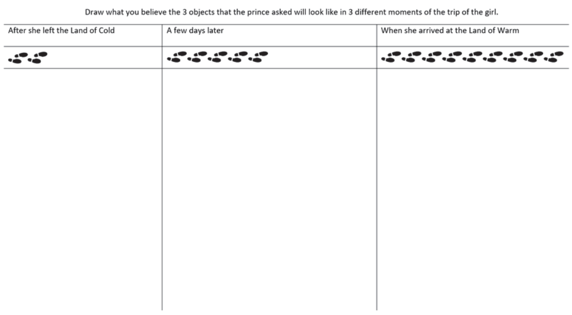
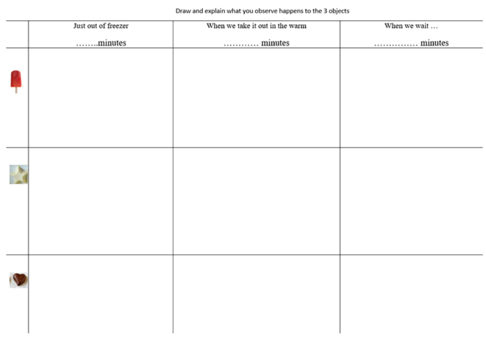
In order to explore the way children express meaning with symbolic and iconic representations in drawings produced during science activities, we will present drawings from a broader project concerning children's understanding of the change of state of matter, specifically melting and solidification [36,44]. The context in which the children's drawings were created was a story narrated to the children by their teachers, and the drawings were produced in the classrooms. The story was developed by the researchers and had no prior illustration. This provided a meaningful context in which young children were encouraged to reflect on the role of temperature in the state of different materials and on a first idea that each of the materials retains its essential identity in the change of state [36]. The full teaching intervention based on the narrated story comprised 5 lessons, each engaging children to produce representations related to the story. The story also engaged children in an experimental challenge to solve a problem. In summary, the story was as follows: In the imaginary environment of a "Land of Warm", a prince posed a challenge: to bring him an ice lolly, a butter star, and a chocolate heart. A girl believed that she could find these objects in the "Land of Cold". Though she found the requested materials in the "Land of Cold", on her journey back to the "Land of Warm" they melted. The story content and the science content were connected so that the children were actively engaged.

In this article, we will focus our attention on 2 drawings. Each drawing was proposed on a document with a scaffolding of the drawing task (Table 1):

Drawing 1: Drawing based on prior knowledge and imagination (Table 1a)—The storytelling engages the character in an imaginary journey from a "Land of Cold" to a "Land of Warm", with objects made of different materials that children are encouraged to draw at three moments of the journey. This drawing is based on prior knowledge that children have about melting and is proposed in order for children to express their initial ideas.

Drawing 2: Drawing based on observation (Table 1b)—Children conduct an experiment to reproduce (model) what happens to the objects during the journey from the "Land of Cold" to the "Land of Warm" and are encouraged to record their observation of the melting objects at three moments (initial state, intermediate state, final state). This drawing is based on observation of the melting phenomena and therefore should reflect the knowledge constructed after observing the result of the experiment.

Table 1. Documents and instructions given to the children to provide scaffolding for (**a**) Drawing 1 and (**b**) Drawing 2.

(a) Drawing 1	(b) Drawing 2
 	
Draw what you believe the 3 objects that the prince asked for will look like in 3 different moments of the trip of the girl: - After she left the Land of Cold - A few days later - When she arrived at the Land of Warm	Draw and explain what you observe happens to the 3 objects - Just out of freezer. . . min (few minutes after) - When we place out in the warm air. . . min (at noon) - When we wait. . . min (the following day)

4.2. Research Protocol

The research has qualitative attributes as well as categories derived from empirical data. Drawings were collected from a group of 28 children, aged 4–5 years old, who attended early childhood settings in a public school in Patras (Greece), and from a group of 18 children, 6–7 years old, who attended Grade 1 of a primary French school in Singapore. All children drew following open instructions given by their teachers in the classroom. The teachers had extensive experience and worked with the researchers to encourage the children to approach the learning objectives during the activities.

For each drawing, we recorded the elements drawn (e.g., materials, concrete or abstract signs) as well as the relationships or changes drawn (e.g., connecting lines, shape/size change) between these elements. We studied the sources of data provided by the drawing activity and sought to identify the representational mode used by the children. Each drawing was coded using the criteria of «iconic» when children attempted to represent distinctive features of reality, physically resembling observable entities, and «symbolic» when children used signs or symbols to stand for something. The codes were sorted under categories that served the discussion concerning the use of drawings in early childhood science education. The study followed thical principles regarding voluntary participation, confidentiality, and the use of data.

5. Results

The analysis of the drawings highlighted a variety of choices made by the children to represent the melting process either from their own idea of the melting objects in the story (D1) or from the observation of melting objects (D2). As mentioned in the research design section, children had to draw in both drawings the objects that were requested by the prince in our story: an ice lolly, a butter star, and a chocolate heart. Children used lines, drops, puddles, etc., to indicate that matter was changing from a solid to a liquid state. We identified several types of signs used by children, which allowed us to categorize iconic or symbolic representations in the drawings. Four categories resulted from the data: (a) drawings that display symbolic representations referring to "conventional" representations (focusing on symbols that young children usually use), (b) drawings that display iconic characteristics (focusing on realistic representations), (c) Drawings that include a mix between symbolic and iconic characteristics (symbolic and iconic modes of representation in the same drawing), and (d) children's production of signs scaffolded by the resources provided (children developed their own symbolic representation scaffolded by our documents). Data from all four categories respond to the first research question. The last category (5.4) includes data that also address the second research question in relation to the symbols that children construct when different semiotic resources are made available by the documents used. In this vein, it was made explicit that the specific research design provided data concerning not only the mode of representations used by the children to communicate meaning about the specific phenomenon but also revealed the acknowledgement of basic factors, such as heat, that are implied in the documents used.

The drawings presented below serve as evocative examples that illustrate some signs used by children. However, it should be noted that the children's drawings rarely belong specifically to a "symbolic" or "iconic" category but instead include signs that are associated with an intention of matching reality or an intention of representing something "other than itself" [28].

5.1. Drawings That Display Symbolic Representations Referring to "Conventional" Representations

We identified a first category of symbolic representations in the choices made by the children to render the melting material with lines and drops. We first focused our attention on the variations of shapes, sizes, and numbers of lines or drops, as well as the colors chosen by the children to reveal the melting process. We used the term "conventional" because this is the type of symbol that young children usually use in their drawings. We then considered some of the explanations the children provided with their drawings and how some common obstacles to the concept of melting are expressed by the children.

Figure 1 presents examples of drawings that were categorized as symbolic representations. In these drawings, the children had to draw the objects of the story exposed to higher temperatures as they were moved from an imaginary "Land of Cold" to a "Land of Warm" (from left to right on the drawings). We noted a change in the size of the objects (GC17 and FC3), with drops expressing the melting process. In the four drawings presented in Figure 1, the melting is depicted with either drops (GC17, FC3, and FC19) or lines (GC25). Such signs do not belong to what can be observed but instead refer to a certain convention of representing drops or rain, evoking the idea of liquid in a common drawing repertoire. There is an interesting choice of symbolic representation in FC3, where the number of drops increases as the objects are melting. In all of the drawings presented in Figure 1, it is also interesting that the lines and drops used by the children to indicate the melting of materials are the same color as the material. One could argue that conservation in color may be an initial statement of conservation of the material. This is not always the case, and several drawings from our sample also show different colors for the same object at different melting stages (see, for example, Figure 2, GC12 or GC21).

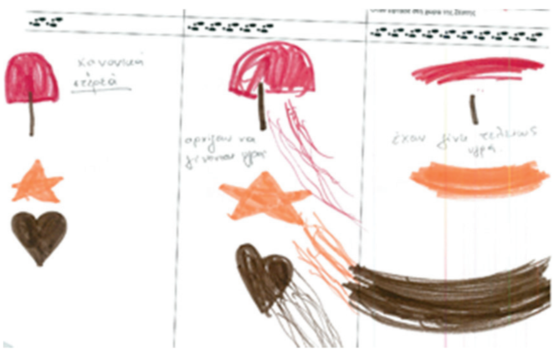
In the last step of the journey, in several drawings, the objects change and are no longer recognizable, with a significant change in shape. In some drawings (such as GC17, Figure 1), the melted ice lolly is depicted as a puddle in which the popsicle stick floats. Children used elements of the context, such as the stick of the ice lolly, left after the ice lolly has melted. In drawing FC19 (Figure 1), the child even used a stick for all three objects, which acts as a signifier of what melts (the chocolate heart, the butter star, and the ice lolly) and what does not melt (the stick).

It seems that children "modify" in their drawings in terms of the color and the shape and size; that is, they use all the important elements of a drawing in order to express the meaning they intend.

Subsequently, we also focused our analyses on the complementarity between the symbolic representation chosen by the children and the comments made by the children (either oral comments written by the teacher or directly recorded by the children). In particular, we highlight the obstacles to understanding the concept of melting that can be identified from the choices of representation and the meaning expressed by some drawings. In Figure 2, drawing GC21 is interesting because it shows the melting process through the change in the size of the object. The child comments "at first it's regular, then it's half because it had melted and eventually it became quite small". However, such a drawing can indicate a focus on the appearance of the object rather than its material composition [38]. A common misunderstanding about melting is also clearly expressed in drawing FC5 (Figure 2). The drops and pools coming from the melting objects are all drawn using the same color, independently from the color of the object melting. The child writes a legend indicating it refers to "small water drops, small water pools". This drawing illustrates the idea suggested by McKeon [39] that some children "consider that melting always involves water and that melting materials such as wax or butter produce water". Finally, for GC12 (Figure 2), we note that the initial objects (placed at the right of the drawing) present a meticulous and colorful design, with a rainbow for the ice lolly. The shape and filling of the object become distorted, with a uniformed color choice for all three objects at the end (left of the drawing). The child's comments allow us to understand that he drew lines to indicate that the objects melted and, in the end, "melted and turned to ashes". We identify here a good example of a confusion between the physical process of fusion and the chemical process of burning [38]. These drawings highlight previously reported obstacles in relation to the conceptual understanding of the melting process and more generally of matter and physical change. However, this supports the idea that they are useful tools that the teacher can use to provide feedback and help the children in their conceptual understanding.

(GC17) *

(FC3) *



(GC25)

(FC19)

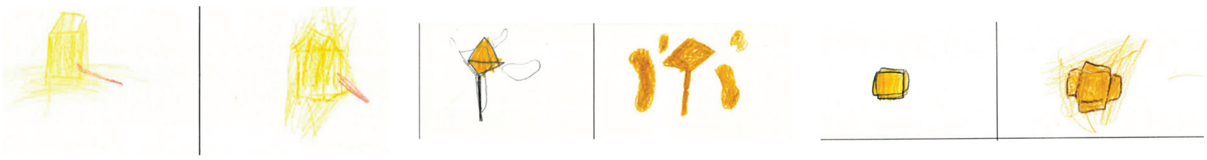
Figure 1. Drawings D1 of the imaginary journey from the Land of Cold to the Land of Warm, with symbolic representations of the melting process of the children: GC17, FC3, GC25, and FC19. * The abbreviation GC stands for "Greek Child" and FC stands for "French Child".

(GC21) (FC5) (GC12)

Figure 2. Examples of drawings expressing meaning-making of the child, which can be an obstacle to understanding the melting process: drawing D1, GC21 and GC12; drawing D2, FC5.

5.2. Drawings That Display Iconic Characteristics

In this category, we highlight children's drawings that represent the materials and the melting process with an attempt to reach a realistic representation. For this, we focus our attention on drawings that use some distinctive features that correspond to what has been seen or observed. The drawings are all from the second situation, Drawing 2 (see examples in Figures 3–5), which is related to the design of the teaching task itself. Drawing 2 followed an experimental situation and, as a result, children could rely on the observation of the actual melting of objects to make their drawing.



(FC1) (FC14) (FC6)

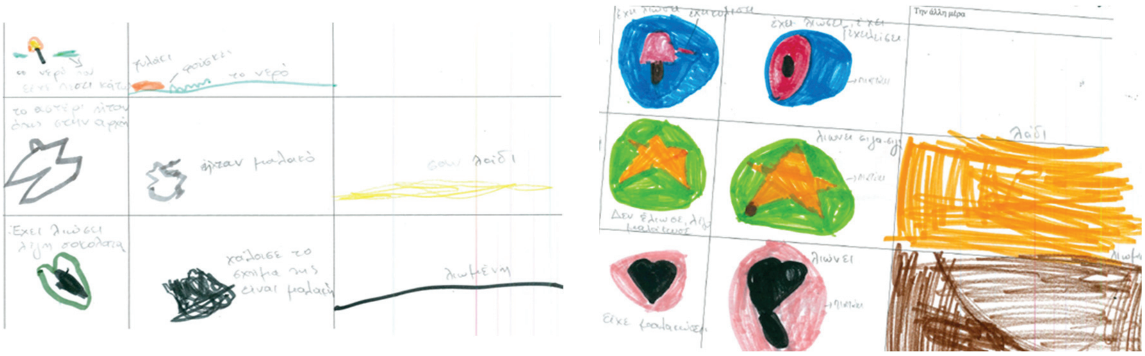
Figure 3. Examples of drawings expressing the three-dimensional aspect of an ice cube melting.

(FC1) (FC14)

(FC6) (FC11)

Figure 4. Examples of drawings with a distinctive feature picturing what was observed in the experiment.

In this attempt to represent what is observed, a number of interesting trends emerge. These trends are useful for identifying drawing strategies that may be more productive than others in terms of science meaning-making and that therefore could receive more support by teachers.



(GC17) (GC25)

Figure 5. Examples of drawings with descriptive details of the observed experiment.

The first trend observed in the drawings is related to explicit efforts made by children to relate their drawing to reality. In other words, we see explicit attempts to draw what was observed. For example, Figure 3 shows different strategies of children to use 3D drawing techniques to draw a cube for the ice cube. Other drawings present some structures to render the effect of volume of the heart shape or star shape. Despite a real difficulty in drawing skills to draw a realistic representation, interesting solutions are found by the children to overcome this difficulty, with 3D drawing techniques which are close to normalized representations of a cube (like drawing FC1) or attempts to show different faces of a cube (like drawing FC6).

A second trend identified in the drawings concerns the depiction of observed details that are specific to a unique experiment. Drawings FC1 and FC14 (Figure 4) are good examples of this. In drawing FC1, the butter star is drawn cut in half. Similar drawings are found amongst four children working together on the same experiment (FC1, FC6, FC8, FC9). In the drawing of child FC6 working with FC1, the child writes "The butter cracked and it was soft". That specific experiment effectively had the butter star split in two parts very quickly. Similarly, the drawing FC14 depicts a flow of liquid chocolate surrounding the still-solid chocolate heart. Once again, similar drawings can be found amongst the group of four children (in which FC11, FC12, FC14, and FC16 participated), whose chocolate heart started melting and flowing along the side of the plate, with a similar pattern to what is depicted in the drawings. These are interesting pieces of evidence that suggest that young children are capable of capturing the realistic features of the experimental situation observed. They were able to represent very clearly a distinctive feature that links the drawing to reality, which Peirce [27] identifies as the main characteristic of an iconic drawing.

The last trend that we want to highlight concerns children's drawings that demonstrate a clear identification of the observed situation. Similarly to what was highlighted in the previous section, interesting meaning-making can be expressed when both drawings and words are used by children to describe what they observe in terms of shape, color, texture, etc. This description of specific aspects gives more realism to the observed experiments and captures, in a descriptive way, what was observed with some degree of accuracy, even if there is a certain distance in the actual realism of the drawing itself. An example of such a drawing is given in Figure 5. Child GC17 drew and described the ice lolly and "water that has fallen down" and then "just the stick and water". For the butter star, "it was as it was in the beginning, then it was soft and like oil at the end", and for the chocolate the child comments "some of the chocolate has melted, then it has lost its shape it is soft and finally melted". Child GC25 drew the materials in the plates as observed and commented that the ice lolly "has melted and flowed (a small line)", and later "it melted and overflowed", with the stick remaining separated. The other materials softened and later melted (oil and melted chocolate).

It is interesting to note that the drawings such as the ones in Figure 5 display less realistic characteristics than drawings such as the ones in Figures 3 and 4. They use more simple drawing techniques, with 2D, the colors not necessarily matching, lines, and more approximate shapes (especially the star in GC17). However, the description of the situation has similar if not more accuracy. An interesting feature used by the children is the analogies to give more meaning to their drawing and relate to known situations ("like oil" for the melted butter). Another interesting aspect to underline in the drawings in Figure 6 is that they have left blank the third part of the melting process for the ice lolly. During the observed experiment, the ice melted earlier than the other materials, and then nothing changed in the remaining time. Engaging children to draw iconic drawings could help them identify what matters in describing and explaining a phenomenon and what details matter less with respect to that phenomenon. For example, the accuracy of the actual shape at the start and whether it is a perfect cube, star, or heart is not so relevant. However, the fact that the objects lose their shape completely as they melt, and with a different temporality, matters more in the description of the phenomenon of melting. To support science meaning-making, it is therefore important for teachers to help children focus their efforts on rendering this "loss of shape" aspect rather than focusing on drawing specific shapes with realistic accuracy. It actually engages children in an intermediate between iconic and symbolic representation. Such drawings can then serve as tools to observe a situation in order to be able to explain the situation.

Figure 6. Example of drawing with both iconic and symbolic representation on the same drawing (GC2, drawing 1).

5.3. Drawings That Include a Mix between Symbolic and Iconic Characteristics

The two categories presented above rely on examples of drawings where either the iconic or the symbolic characteristics were explicitly found on a drawing. However, in some drawings, both symbolic and iconic modes of representation can be identified in the same drawing. The drawings reveal that children are flexible in the way they choose to present something. They take the liberty to stick to reality or interpret reality depending on the context. In particular, we would like to highlight two tendencies that we identified.

The first tendency is the presence of clues that refer to symbolic or iconic modes of representation on the same drawings. An interesting example can be observed in the drawing of GC2 (Figure 6). The child draws the ice lolly melting as if it was running and changing shape. However, in the same drawing, a more symbolic representation is used for the melting of butter and the melting of chocolate. A code with lines is used for the other two materials. In such cases, the ice lolly probably refers to an experience of seeing a melting lolly, but for the butter heart and chocolate star, the children are less likely to have the experience of observing melting butter or melting chocolate. The memory they convene for ice melting does not transfer to other materials. They are trying to represent melting but come up with different representations. When representing something that is known, such as ice melting, they have a repertoire that they can use to produce an iconic representation. The melting of other materials is less commonly observed in children's everyday life or even in classroom situations, and as a result, it is not formed in their mental representation yet. At this point it is interesting to comment that the child uses two different ways to represent the melting, which are linked to his experience. Thus, the representation of an "ice lolly melting" is specific to the ice lolly and not a representation of "melting" in general.

The second tendency was observed when drawings from the same child depicted a clear difference between drawing 1 and drawing 2 in terms of representation. Considering the nature of the task for drawing 1 (drawing from imagination) and for drawing 2 (drawing from observation), it was interesting to observe a shift from symbolic representations in drawing 1 to more iconic representations in drawing 2.

An example can be found in the drawing of GC16 (Figure 7), where the factor of time appears to be a relevant element for the child. In drawing 1, the child draws the materials frozen, then having lost their shape, and finally as puddles that had melted completely, with a string similarity from one object to another. In drawing 2, while observing the melting process of each object, there is a variation in the time that each one takes to melt, e.g., he drew the ice lolly melting, and later, it melted completely and "became juice", while the butter at first "did not melt", then "melted a little", and then was a "melted liquid".

(GC16, Drawing 1) (GC16, Drawing 2)

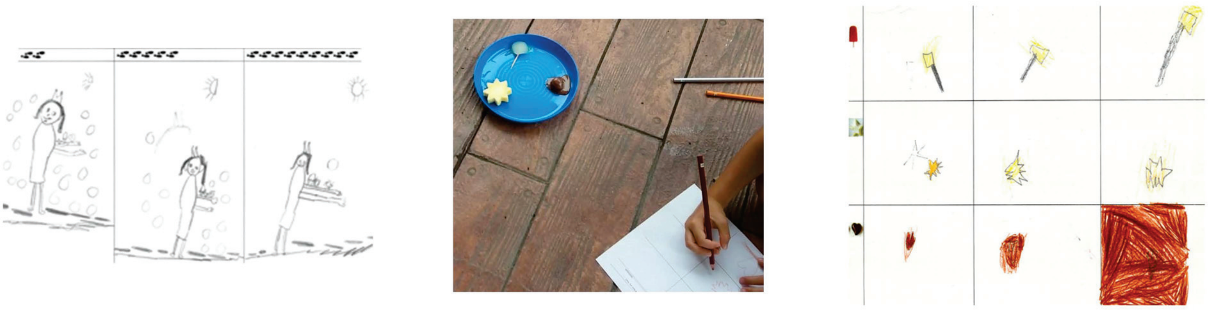
Figure 7. Drawings of the child GC16.

Another example can be found in Figure 8. In drawing 1, child GC19 draws the melting process by disfiguring the objects and showing that they are distorting their shape, with a similar process for all three objects (and three materials). After observing the experiment, there is a shift in his drawing, with several interesting characteristics. He introduced a different temporality in the melting process depending on the material, with both drawings and comments indicating that the ice lolly melted "sooner", while the butter and the chocolate "had melted a bit" and "was soft". Rather than a distortion of shape used to depict the melting process in drawing 1, he uses lines to indicate that it "melted and flowed". However, for drawing 2, it is interesting to note that the child draws lines to indicate the final phase of melting, but there are drops introduced as intermediates between the initial state (solid objects) and the final state (lines). Such drawings reveal a flexibility in the way children choose to present something depending on the context. In this case, the representation of the initial state and the final state seemed straight forward, but the introduction of drops to represent the process of melting in itself was a way for the child to go beyond what was directly observed in the experiment. Children find solutions to the type of task asked for in the drawing, and even when observing the phenomena, they mix iconic and symbolic modes of representation to make sense of the phenomena observed.

A last example is presented in Figure 9. In these drawings, we observe a clear shift. In drawing 1, there is a focus on the story, representing the character of the journey, with very distinctive features using symbols to render the concept of temperature changing. In drawing 2, there is an effort to render observed features from the experiment. In particular, there are attempts to draw a cube for the ice lolly similar to the experiment rather than a more prototypical rounded shape. As objects melt, they are depicted in a puddle that grows in size within a different time frame, depending on the object (the chocolate hearts melt first).

(GC19, Drawing 1) (GC19, Drawing 2)

Figure 8. Drawings of the child GC19.



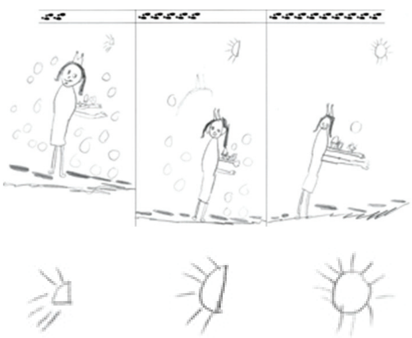
(FC13, Drawing 1) (Experimental situation) (FC13, Drawing 2)

Figure 9. Drawings of child FC13 and experimental situation during drawing 2.

Such results are interesting to bring a reflection on the scaffolding that can be provided to young children in their drawing and the support it gives to use symbolic drawings or iconic drawings, depending on the nature of the scientific activity associated.

5.4. Children's Production of Signs Scaffolded by the Resources Provided

Finally, some drawings revealed interesting propositions of symbolic representations by the older group of children (6–7 years old). These propositions were neither suggested by the didactic situation presented by the teacher nor by observations of physical or natural phenomena. We identified several drawings where children define their own rules of representation, conveying meaning with a choice of original codes combining conventional forms of representation. In particular, children transcribed their representation of the idea of "Land of Cold" and "Land of Warm" (Figure 10). It is important to note here that the story told by the teacher was narrated verbally, with no illustration to support its understanding. However, the journey of the main character from an imaginary "Land of Cold" to an imaginary "Land of Warm" was intended to draw an analogy referring to the change of temperature with time. As shown in Figure 10, FC13 uses the sun to express an idea of proportion of "heat", with a quarter of the sun for the Land of Cold, and a full sun for the Land of Warm. This symbolic representation brings a numerical dimension to the change of temperature, conveying the idea that a given temperature is associated with a given proportion of sun. Interestingly, the choice made by the child is referring to a scientific conventional representation of pie charts. Other drawings use the size of the sun as a signifier of temperature, with a sun drawn significantly and consistently larger in the "Land of Warm" (FC2, Figure 10). Children added objects conventionally referring to cold and warm temperatures, such as ice cubes and flames (FC2, Figure 10). These drawings suggest that the children consider a rise in temperature as a condition necessary to the melting process.



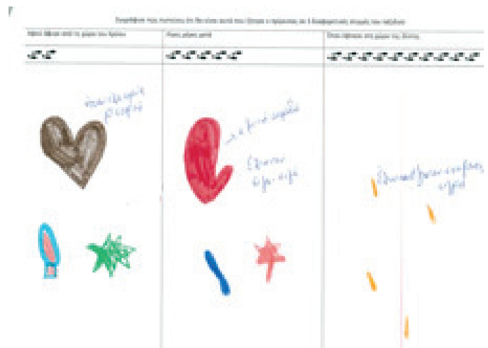
(FC13)

(FC2)

Figure 10. Drawing 1 of children FC13 (**left**) and FC2 (**right**), with a zoom of the representation of the sun on each drawing, representing three steps of the journey from an imaginary Land of Cold to an imaginary Land of Warm.

Some children propose interesting ideas to represent changes in different stages and over a period of time. In Figure 11, child FC4 draws an accumulation of scribbled lines, gradually blurring the objects that express in a meaningful way the gradual process of melting. Another example of a personalized way of expressing the melting process can be found in the drawing of child GC13 (Figure 11). This child first draws the materials indicating that they are all cold and solid; then, she draws the chocolate heart in half, expressing that "it melted slowly slowly", and only draws the stick from the ice lolly. For the last step, GC13 draws only drops to show "they melted, they became drops of liquid". Two ideas are interesting here. The passing time is explicitly expressed by the child, and the idea that different materials might not take the same time to melt.

(FC4)



(GC13)

Figure 11. Drawing 1 of children FC4 (**left**) and GC13 (**right**) representing three steps of the journey from an imaginary land of cold to an imaginary land of warm.

The last interesting feature that we want to highlight relates to the focus of the drawing chosen by the children. In particular, some children choose to draw the character of the story holding the objects as well as the objects melting. In Figure 12, child FC15 draws the character of the story in her journey, holding a drawing that depicts the objects melting. Symbolic representations of drops already described in Section 5.1 are used. But it is interesting to note that the melting process is observed through the eyes of the character of the story. In the case of the child (GC8), the character of the story holds the objects in her hands first "without melting", then using lines because they "melted a little", and finally with an undefined shape because they "melted so much". The comments say "The girl left delighted with what the prince asked for without having melted, then they melted a little and then they melted too much". FC15 uses the absence and different size of the sun to indicate the temperature change. GC8 and FC1 divided the worksheet into more sections than originally planned. Two timelines are functioning in parallel. The bottom part depicts the journey of the girl, and the top part depicts what happens to the objects themselves during this journey.

(FC15) (GC8) (FC1)

Figure 12. Drawing 1 of children FC15 (**left**), GC8 (**middle**), and FC1 (**right**), representing three steps of the journey, with a focus on the character of the story.

6. Discussion

Through their drawings, children intentionally elaborate on previous experience and express new ideas. Their early endeavors «reveal their ability to make, either explicit or implicit, choices in expressing and communicating what is salient and essential for them» [31] (p. 2). In this study, we sought to highlight the importance of using drawing to reveal children's rich repertoires of signs and symbols in science. Using melting as a science subject, we asked young children to draw, linking their drawings to two different tasks: the narration of a story and the observation of an experiment.

6.1. What Mode of Representations Is Used by the Children to Communicate Meaning in Different Drawings during a Science Activity?

Concerning our first research question, we showed that the context of the drawing triggered different representational modes. In most of the first drawings, which were linked to the story and in which children had to put forward their experience as well as their imagination, they used a symbolic mode. In most of the second drawings, which were linked to the observation of an experiment, children used an iconic mode. We mainly used the distinction between the iconic and the symbolic mode of representation in order to highlight the connection with the scientific content. We did not carry on with further subcategories describing the drawings, such as actions, events, persons, or point of view, which often overlap, as the purpose of the drawing was specific and was related to the nature of the task (storytelling and observation). Therefore, we identified entities or processes represented through iconic and symbolic modes in children's drawings, which were classified into four categories as presented in the results.

More specifically, the first category refers to drawings drawn by the children using symbolic representations and signs, which can represent a "conventional" drawing repertoire (drops, lines) including variations of shapes, sizes, and colors chosen. At the same time, drawings where children were able to use elements of the context (stick of ice lolly) to convey their ideas were also classified in this category. The freedom provided by the drawing seemed to make it easier for some children to express their way of thinking about the phenomenon and to reveal the difficulties in their conceptual understanding of melting. For example, some children revealed their ideas concerning melting as a change of the materials' size, as burning, or as a procedure resulting in water production, which are ideas found in the literature [38,39]. The drawings of the second category had more iconic characteristics, which indicated that when children observe the phenomenon they can focus on specific elements and attribute details in their drawing (e.g., the material that softened before melting, the butter that is like oil, the time it takes for each material to melt). It is worth noting that in the second drawing there is the illustration of the final stage of melting in two ways: as a line (which probably responds to a side view) or as a puddle (which probably responds to a top view) (Figure 5). Therefore, depending on the nature of the task of drawing, the first category included more drawings from the first task (imaginary journey) while the second category included more drawings from the second task (observation). This finding is aligned with other studies that report children's increasing awareness of what constitutes a science representation, when science is represented as content reduced to its most general aspects in terms of detail, color, shape, and setting [7,14,20]. As already mentioned, the categories relating to the content of a drawing are often not exclusive, but a drawing may include elements from different categories and modes. The third category reflects this flexibility in children's drawing depending on the context. The same child in the same drawing may use both modes or move easily from one mode to the other, using as many elements of a visual language as possible to clearly state what he or she is thinking and observing. This dimension of children's drawings was also expressed by Deguara and Nutbrom [1] and Areljung et al. [7]. This variation also shows the possibility of both modes being used by teachers. The last category included the drawings where children choose their own codes of representation, as the narration of the story in which the drawings were integrated allowed the children to be more actively involved and communicative. The story creates a context in which each child could use the collective meaning to elaborate and bring to the fore the individual [45]. Storytelling engages children's interest in the science topic by providing a context, stimulating the children to share some ideas and using language that is within their experiences [46]. Teachers use stories that emphasize particular aspects of a phenomenon or that are open-ended so that the children can develop their own ideas [36,47]. What is particularly interesting is that the children found new ways to represent factors in the story, such as the change in temperature and the time passing. The question of passing time was transferred to the question of travelling a distance, which could be easier to grasp for young children. This journey was sufficiently evocative for children to express meaningful ideas about melting.

6.2. Which Symbols Do Children Create through Their Drawings When Different Semiotic Resources Are Made Available?

Although the decisions about how to represent each element were made by the children, the specific documents provided to children in order to draw played a crucial role in these decisions. An interesting aspect of this research is the acknowledgement of the use of various symbols because of the scaffolding provided to the children by the documents used. For example, the fact that it was decided by the researchers to capture three different moments of both the journey and the observation of the phenomenon may have in a way suggested to the children the idea of a process in time or a change. Monteira et al. [14] refer to "structural scaffolding", describing those elements included by the teacher as part of a template. As the process of representing involves the choice of semiotic resources, teachers may convey representational conventions through the semiotic resources they provide [7]. In our study, several children in their first drawing, guided by the documents, decided to identify more specifically each phase of the drawing; they used different symbols for cold and heat, such as different proportions of sun, ice cubes, and flames (FC2, FC13), or they drew a dividing headline with the differentiations of the melting process (FC1). They developed their own symbolic representation to express the idea of temperature levels from colder temperature to warmer temperature. These ideas have been found difficult to identify for young children in previous research [41,42].

In this perspective, science drawings of young children are considered as a means to grasp first disciplinary affordance with the use of signs that bear the potential to represent observable experimental situations and abstract concepts of science (arrows, small diagrams, chosen schematic representations, etc.). Airey and Linder [48] (p. 99) define disciplinary affordance as "the agreed meaning making functions that a semiotic resource fulfils for the disciplinary community". Of course, what is referred to as a disciplinary community in the previous quote does not suggest the same objects for the physics concepts at the university level as studied by Airey and Liney [48] as for preschool children's early initiation to science. But we argue here that it is meaningful for young children to be guided in a meaning-making process that can help them gain a first understanding of a physical concept. This proposition is following previous work on young children's learning of physics concepts with support from the teacher and appropriate teaching interventions [49].

Drawing has culturally and socially transmitted conventions, which children come to know by imitating or reproducing the graphic models available in their everyday life [50]. By combining their own symbols with symbols they are familiar with from their everyday environment (numbers, letters, traffic signs, etc.), children develop codes, which they adapt and improve. In other words, they gradually seek to improve communication by following conventions and developing their ability to represent. At the same time, the deliberate effort to represent specific elements of a phenomenon or various relations and changes demands increased mental activity from children. If we accept that children's engagement with drawing is not fixed but constantly evolving, it is important that children are able to participate in a variety of drawing activities (where semiotic resources may be provided or not) in which they have the opportunity to further explore the relationship between symbols and meaning.

6.3. Limitations

The study has limitations that should be considered in relation to future research. As is the case in most qualitative research, the number of participants from each country is limited; therefore, further investigation is needed for different classroom contexts, cultures, and ages. In addition, using drawing as a research method has challenges when analyzing and interpreting the visual documents. Considering this, in an effort not to shift the focus away from the mode of representation, we did not analyze the dialogues between children or teachers; perhaps this choice limited the possibility of capturing the richness of all children's ideas. Finally, it should also be considered that though drawing is a useful tool, it can be complementary to other ways of communication or classroom practices; thus, the teacher's attitude plays an important role in encouraging children who might have difficulty to express their views fully, especially if they do not have advanced design skills or enjoy drawing activities.

7. Conclusions

The analysis of young children's drawings showed that children find solutions, sometimes unexpected, to produce effective representations. In other words, they use signs that can be symbolic or iconic so that certain characteristics of their drawing are recognized without ambiguity. Thus, we consider that the use of drawing in science with young children allows them to express a greater variety of ideas through conventional and unconventional signs and symbolic resources.

When we discuss the use of drawing in science education, we have to bear in mind that teachers have an additional challenge to overcome. The desire of children to draw as closely as possible to reality a concept or phenomenon poses difficulties and often obscures the real understanding on the part of the child. The teachers need to help children in the context of the representation of scientific concepts to understand that it is the representation of the essential elements that contributes to understanding, thereby helping children to identify the key features of a situation and not become trapped in trying to depict a real picture. The use of relevant sources can therefore contribute in this direction. Often what we observe happening in classrooms is contradictory: on the one hand, the drawing is used extensively in the classroom for various reasons, and on the other hand, it does not seem to receive the proper amount of attention from teachers [22]. As Imafuku and Seto [51] argue, representations and images are related to children's drawing activities, and drawing is thought to involve complex cognitive abilities. They claim that representation ability and imagination are the cognitive bases of children's drawings. Considering the fact that language and representational abilities are learned in the context of relationships with others, drawing may also develop in the classroom context. In this perspective, drawing activity is not only a way that children use to express their ideas, it is much more: it is a language that has potential and can evolve. It is a visual language and can be a powerful learning resource if used appropriately in the classroom [18].

8. Implications

It is necessary to adopt strategies in the classrooms that do not hinder children's expression and communication through drawing and instead enhance them. Inadequate materials, limited time, strict guidance, and pointless judgement of drawing ability are some of the practices of teachers that do not contribute to teachers' appreciation of drawing as a learning tool [22] and acknowledging the essence and importance of drawing as a language. It is a challenge for a teacher to be able to be a genuine supporter of children and at the same time a guide. Acknowledging that children know more than they usually say, drawing is an effective strategy for eliciting children's thinking and therefore a valuable tool for planning teaching and learning. In this perspective, teachers should a) better understand how children use drawing (expressing ideas, constructing meaning), b) select which aspects of symbolic activity to reinforce in the classroom, and c) use drawings to monitor the development of symbolic competence. Educators who reflect on young children's drawings can consider what kinds of visual representations need to be encouraged with further rich curriculum content.

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References

1. Deguara, J.; Nutbrown, C. Signs, symbols and schemas: Understanding meaning in a child's drawings. *Int. J. Early Years Educ.* **2018**, *26*, 4–23. [CrossRef]
2. Hope, G. *Thinking and Learning through Drawing in Primary Classrooms*; Sage: London, UK, 2008.
3. Einarsdottir, J.; Dockett, S.; Perry, B. Making meaning: Children's perspectives expressed through drawings. *Early Child Dev. Care* **2009**, *179*, 217–232. [CrossRef]
4. Prain, V.; Tytler, R. Learning Through Constructing Representations in Science: A framework of representational construction affordances. *Int. J. Sci. Educ.* **2012**, *34*, 2751–2773. [CrossRef]
5. Hall, E. Mixed messages: The role and value of drawing in early education. *Int. J. Early Years Educ.* **2009**, *17*, 179–190. [CrossRef]
6. Papandreou, M. Communicating and thinking through drawing activity in early childhood. *J. Res. Child. Educ.* **2014**, *28*, 85–100. [CrossRef]
7. Areljung, S.; Skoog, M.; Sundberg, B. Teaching for Emergent Disciplinary Drawing in Science? Comparing Teachers' and Children's Ways of Representing Science Content in Early Childhood Classrooms. *Res. Sci. Educ.* **2022**, *52*, 909–926. [CrossRef]

8. Delserieys, A.; Impedovo, M.A.; Fragkiadaki, G.; Kampeza, M. Using drawings to explore preschool children's ideas about shadow formation. *Rev. Sci. Math. ICT Educ.* **2017**, *11*, 55–69.
9. Chachlioutaki, M.E.; Pantidos, P.; Kampeza, M. Changing semiotic modes indicates the introduction of new elements in children's reasoning: The case of earthquakes. *Educ. J. Univ. Patras UNESCO Chair* **2016**, *3*, 198–208. [CrossRef]
10. Chang, N. What are the roles that children's drawings play in inquiry of science concepts? *Early Child Dev. Care* **2012**, *182*, 621–637. [CrossRef]
11. Papandreou, M.; Birbili, M. Not just a recreational activity: Giving artmaking the place it deserves in early childhood classrooms. *Educ. J. Univ. Patras UNESCO Chair* **2017**, *4*, 94–106. [CrossRef]
12. Robbins, J. 'Brown paper packages'? A sociocultural perspective on young children's ideas in science. *Res. Sci. Educ.* **2005**, *35*, 151–172. [CrossRef]
13. Rogoff, B. *The Cultural Nature of Human Development*; Oxford University Press: New York, NY, USA, 2003.
14. Monteira, S.F.; Jiménez-Aleixandre, M.P.; Siry, C. Scaffolding Children's Production of Representations Along the Three Years of ECE: A Longitudinal Study. *Res. Sci. Educ.* **2022**, *52*, 127–158. [CrossRef]
15. Lange-Küttner, C.; Thomas, G.V. (Eds.) *Drawing and Looking: Theoretical Approaches to Pictorial Representation in Children*; Harvester Wheatsheaf: New York, NY, USA, 1995.
16. Wood, E.; Hall, E. Drawings as spaces for intellectual play. *Int. J. Early Years Educ.* **2011**, *19*, 267–281. [CrossRef]
17. van Oers, B. On the Narrative Nature of Young Children's Iconic Representations: Some evidence and implications. *Int. J. Early Years Educ.* **1997**, *5*, 237–245. [CrossRef]
18. Brooks, M. Drawing, Visualisation and Young Children's Exploration of "Big Ideas". *Int. J. Sci. Educ.* **2009**, *31*, 319–341. [CrossRef]
19. Hopperstad, M.H. Relationships between children's drawing and accompanying peer interaction in teacher-initiated drawing sessions. *Int. J. Early Years Educ.* **2008**, *16*, 133–150. [CrossRef]
20. Monteira, S.F.; Jiménez-Aleixandre, M.P.; Martins, I. Cultural semiotic resources in young children's science drawings. *Cult. Stud. Sci. Educ.* **2024**, *19*, 295–315. [CrossRef]
21. Longobardi, C.; Quaglia, R.; Iotti, N.O. Reconsidering the scribbling stage of drawing: A new perspective on toddlers' representational processes. *Front. Psychol.* **2015**, *6*, 1227. [CrossRef]
22. Anning, A.; Ring, K. *Making Sense of Children's Drawings*; Open University Press: Maidenhead, UK, 2004.
23. Hayes, D.; Symington, D.; Martin, M. Drawing during science activity in the primary school. *Int. J. Sci. Educ.* **1994**, *16*, 265–277. [CrossRef]
24. Areljung, S.; Due, K.; Ottander, C.; Skoog, M.; Sundberg, B. Why and how teachers make use of drawing activities in early childhood science education. *Int. J. Sci. Educ.* **2021**, *43*, 2127–2147. [CrossRef]
25. Schnotz, W. Integrated model of text and picture comprehension. In *Cambridge Handbook of Multimedia Learning*, 2nd ed.; Mayer, R.E., Ed.; Cambridge University Press: Cambridge, UK, 2014; pp. 72–103.
26. Opfermann, M.; Schmeck, A.; Fischer, H.E. Multiple Representations in Physics and Science Education—Why Should We Use Them? In *Multiple Representations in Physics Education*; Treagust, D.F., Duit, R., Fischer, H.E., Eds.; Models and Modeling in Science Education; Springer: Cham, Switzerland, 2017; Volume 10, pp. 1–22.
27. Peirce, C.S. Logic as semiotic: The theory of signs. In *The Philosophical Writings of Peirce*; Buchler, J., Ed.; Dover: Mineola, NY, USA, 1955; pp. 98–119.
28. DeLoache, J.S. Becoming symbol-minded. *Trends Cogn. Sci.* **2004**, *8*, 66–70. [CrossRef] [PubMed]
29. Driver, R.; Guesne, E.; Tiberghien, A. Some features of children's ideas. In *Children's Ideas in Science*; Driver, R., Guesne, E., Tiberghien, A., Eds.; Open University Press: Philadelphia, PA, USA, 1985; pp. 193–201.
30. Delserieys, A.; Kampeza, M. Le dessin comme outil d'enseignement-apprentissage en sciences à l'école maternelle. *Rech. Didact. Sci. Technol.* **2020**, *22*, 93–122. [CrossRef]
31. Papandreou, M. Young children's representational practices in the context of self-initiated data investigations. *Early Years* **2022**, *42*, 371–387. [CrossRef]
32. Boilevin, J.-M.; Delserieys, A.; Ravanis, K. (Eds.) *Precursor Models for Teaching and Learning Science During Early Childhood*; Contemporary Trends and Issues in Science; Springer: Cham, Switzerland, 2022.
33. Ravanis, K. Early childhood science education: State of the art and perspectives. *J. Balt. Sci. Educ.* **2017**, *16*, 284–288. [CrossRef]
34. Raven, S.; Wenner, J.A. Science at the Center: Meaningful Science Learning in a Preschool Classroom. *J. Res. Sci. Teach.* **2023**, *60*, 484–514. [CrossRef]
35. Kambouri-Danos, M.; Ravanis, K.; Jameau, A.; Boilevin, J.M. Precursor models and early years science learning: A case study related to the water state changes. *Early Child. Educ. J.* **2019**, *47*, 475–488. [CrossRef]
36. Kampeza, M.; Delserieys, A. Approaching change of state in early childhood education: The design of a teaching intervention based on storytelling. *Educ. J. Univ. Patras UNESCO Chair* **2019**, *6*, 89–98.
37. Paik, S.-H.; Cho, B.-K.; Go, Y.-M. Korean 4- to 11-Year-Old Student Conceptions of Heat and Temperature. *J. Res. Sci. Teach.* **2007**, *44*, 284–302. [CrossRef]
38. Rahayu, S.; Tytler, R. Progression in primary school children's conception of burning: Toward an understanding of the concept of substance. *Res. Sci. Educ.* **1999**, *29*, 295–312. [CrossRef]
39. McKeon, F. Materials. In *Developing Primary Science*; Sharp, J., Ed.; Learning Matters: Exeter, UK, 2004; pp. 95–109.

40. Arnold, M.; Millar, R. Learning the scientific "story": A case study in the teaching and learning of elementary Thermodynamics. *Sci. Educ.* **1996**, *80*, 249–281. [CrossRef]
41. Pahl, A.; Fuchs, H.U.; Corni, F. Young Children's Ideas about Heat Transfer Phenomena. *Educ. Sci.* **2022**, *12*, 263. [CrossRef]
42. Ravanis, K. Mental representations and obstacles in 10–11 years old children's thought concerning the melting and coagulation of solid substances in everyday life. *Presch. Prim. Educ.* **2013**, *1*, 130–137. [CrossRef]
43. Kampeza, M.; Vellopoulou, A.; Fragkiadaki, G.; Ravanis, K. The expansion thermometer in preschoolers' thinking. *J. Balt. Sci. Educ.* **2016**, *15*, 185–193. [CrossRef]
44. Kampeza, M.; Delserieys, A. Acknowledging drawing as a mediating system for young children's ideas concerning change of state of matter. *Rev. Sci. Math. ICT Educ.* **2020**, *14*, 105–124.
45. Hakkarainen, P.; Bredikyte, M. Playworlds and Narratives as a Tool of Developmental Early Childhood Education. *Psikhologicheskaya Nauka Obraz.-Psychol. Sci. Educ.* **2020**, *25*, 40–50. [CrossRef]
46. Fleer, M.; Hardy, T. How can we find out what 3 and 4 year olds think? New approaches to eliciting very young children's understandings in science. *Res. Sci. Educ.* **1993**, *23*, 68–76. [CrossRef]
47. Kampeza, M.; Ravanis, K. Children's understanding of the earth's shape: An instructional approach in early education. *Skholê* **2012**, *17*, 115–120.
48. Airey, J.; Linder, C. Social Semiotics in University Physics Education. In *Multiple Representations in Physics Education*; Treagust, D.F., Duit, R., Fischer, H.E., Eds.; Models and Modeling in Science Education; Springer: Cham, Switzerland, 2017; Volume 10, pp. 95–122.
49. Delserieys, A.; Jegou, C.; Boilevin, J.-M.; Ravanis, K. Precursor model and preschool science learning: Efficiency of a teaching intervention on shadow formation. *Res. Sci. Technol. Educ.* **2018**, *36*, 147–164. [CrossRef]
50. Pinto, G.; Accorti Gamannossi, B.; Cameron, C. From scribbles to meanings: Social interaction in different cultures and the emergence of young children's early drawing. *Early Child Dev. Care* **2011**, *181*, 425–444. [CrossRef]
51. Imafuku, M.; Seto, A. Cognitive basis of drawing in young children: Relationships with language and imaginary companions. *Early Child Dev. Care* **2021**, *192*, 2059–2065. [CrossRef]

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Article

Thematic Teaching of Augmented Reality and Education for Sustainable Development in Preschool—The Importance of 'Place'

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Abstract: In this study, we report on a case study of two Swedish preschool teachers' first experiences of teaching sustainable development goals through the innovative use of augmented reality. Their statements about thematic work, children's agency, teachers' perspective, and augmented reality were analysed qualitatively through a theoretical framework based on transduction and place. The innovative use of augmented reality related to the importance of children's agency in their exploration of local places associated with sustainable development goals is elaborated on, especially with the value of treating augmented reality as a 'what', or content, in teaching before it can be used as a 'how', or tool, for teaching sustainable development. It is seen in this exploratory study that transducing meaning between different representations such as physical places and the sustainable development goals in augmented reality applications opens up fruitful discussions regarding, for example, democracy aspects and source criticism between children and preschool teachers. Results indicate that the introduction of augmented reality technology is also worth pursuing in early-year teaching.

Keywords: preschool teachers; sustainable development; augmented reality; transduction; place

1. Introduction

Digitalisation is nowadays a natural part of society and as a result, it has gained an increasingly prominent place in early childhood education around Europe. However, even though the use of augmented reality (AR) has increased in the field of education, only a very limited number of studies have been carried out in preschool [1,2]. Furthermore, studies reporting on the views of preschool teachers on working with AR are lacking. In this article, we report on an exploratory case study of the experiences of two preschool teachers in teaching sustainable development with AR in Sweden. The content of sustainable development was found to fit well with the aim for digitalisation in the current national curriculum for preschool in Sweden.

Education should also give children the opportunity to develop adequate digital skills by enabling them to develop an understanding of the digitalisation they encounter in everyday life. Children should be given the opportunity to develop a critical, responsible attitude towards digital technology, so that eventually they can see opportunities and understand risks, and also be able to evaluate information [3].

Additionally, sustainable development has its base in critical reflections and the question of how we can meet today's human needs without compromising the ability of future generations to meet their needs [4]. The idea is often described as having three dimensions: economic, social, and ecologic. In 2015, all the countries in the United Nations adopted the 2030 Agenda for Sustainable Development. The 17 goals seek to end poverty and hunger, realise human rights, and ensure the protection of natural resources on the planet. In 2022, a report was launched by the Stockholm Environment Institute and the Council on Energy, Environment, and Water with recommendations for actions guided by 27 experts in sustainable development. One of the ten key statements addresses that human–nature connectedness should be strengthened in social norms and how we live our everyday lives (e.g., by increasing nature-based education for children and youth). Education, from pre-school to higher education, has been recognised as a key factor in the development of a life-long engagement with sustainability, and transformation, or system changes, is necessary [5]. In line with this, five priority areas in education for sustainable development (ESD) were highlighted in UNESCO's Global Action Programme: (1) advancing policy; (2) transforming learning environments; (3) building capacities of educators; (4) empowering and mobilising youth; and (5) accelerating local-level actions [6].

1.1. Sustainable Development and Digitalisation in Swedish Preschool

In Sweden, preschool is part of the educational system as a voluntary form of school for children from one to five years of age. According to the statistics, nearly 86% of children in that age range participate, and the cost is nationally subsidised. Preschool teachers (3.5 years university study) are responsible for pedagogical activities, aiming for play and learning in content areas described in the national curriculum for preschool [3]. In the latest version of the curriculum, there is an increased focus on several aspects of sustainable development (SD). Examples of what the preschool should provide each child with the conditions to help them develop, and related to the present study, are:

- An understanding of democratic principles and the ability to cooperate and make decisions in accordance with them;
- A growing responsibility for and interest in sustainable development and active participation in society;
- An understanding of how different choices people make in everyday life can contribute to sustainable development;
- An understanding of relationships in nature and different cycles in nature, and how people, nature, and society affect each other [3].

There are also several goals related to digitalisation:

- An interest in stories, pictures, and texts in different media, both digital and other, and their ability to use, interpret, question, and discuss them;
- An ability to explore, describe with different forms of expression, ask questions, and discuss science and technology;
- An ability to discover and explore technology in everyday life [3].

It is further expressed that the work team should "create conditions for children to develop their ability to communicate, document and convey occurrences, experiences, ideas and thoughts using different forms of expression, both with and without digital tools" [3].

Hence, Swedish preschool is goal-directed, which indicates a continued development of early childhood education didactics [7–10], with didactic in the Scandinavian sense, meaning that teachers develop knowledge of both the content in focus and how to provide favourable conditions for children's learning [11–14]. The argument for science by Fleer, "The challenge goes beyond content knowledge to teacher beliefs and pedagogy practices" [11] (p. 1074), still holds.

1.2. Thematic Teaching

The didactic of combining two or more different contents in teaching is well-established in the Swedish preschools' tradition of thematic teaching, where the contents are contextualised and studied for an extended time. Teaching with a thematic approach entails including the children's experiences and specific situations [15,16]. Hence, the teaching would strive to acknowledge the children's perspectives and relate to the everyday phenomena that they are interested in [17]. Here, we adopted the classification scheme for thematic teaching in early childhood introduced in [16], consisting of the constructs multidisciplinary, interdisciplinary, and transdisciplinary teaching, from the literature on STEM

(Science, Technology, Engineering, and Mathematics) education cf. [18–20]. A multidisciplinary approach means that concepts from the included content areas are taught separately, in other words, AR and ESD would be taught at different times, and the integration and thematic application would be more or less left to the children on their own. The interdisciplinary approach is characterised by content from different areas being intertwined and linked during teaching. In our case, this would entail that AR and ESD are taught simultaneously and thematically applied in a second step. The transdisciplinary approach takes the thematisation a step further, with concepts and skills being taught based on a real-world situation. The first step would be to select a phenomenon to investigate and learn about, and the second step would include the contents in AR and ESD and intertwine problem-solving and teaching.

1.3. Transduction and the Importance of Place

As stated above, transforming learning environments, empowering and mobilising youth, and accelerating local-level actions are all strategies in UNESCO's Global Action Programme (2020). They all involve the important aspect of *place* because, as commented by Geertz [21], "[N]o one lives in the world in general" (p. 259). Places are profoundly pedagogical as centres of experience, where our identities are shaped and where we learn about how the world works [22]. Casey [23] emphasises the deep connection between place and self when he states, 'there is no place without self and no self without place', and Scott [24] expresses that a sense of place represents the vital link between where we live and who we are.

The meaning of place, however, varies across different disciplines. Hence, from an ecological standpoint, places are alive, while from the mathematical or computational point of view, place could be a point or a screen. From a model-based view [25], or viewed from a cultural or psychological perspective, one person's experience of a place would depend on prior experiences and might be different from another person's (i.e., one would experience different 'places'). Grünewald describes the problem with traditional schooling not recognising the importance of experiencing places. He discusses that places are produced by people, but at the same time, places introduce certain ways of thinking about the world. To address this issue, Grünewald proposed a critical pedagogy of place, a pedagogy that relates to the students' experience of the world and improves the quality of life for people and communities [26]. This critical pedagogy is ecologically as well as socially grounded and emphasises our relationships to each other and to our socio-ecological places. Furthermore, the critical pedagogy of place aims at teachers and students taking social action to improve the social and ecological life of both local and distant places [26] (Grünewald, 2003b), and can thus be viewed as a pedagogy for sustainable development.

In order to help learners make fruitful connections between teaching content and different places, the use of representations and different semiotic resources has become part of the teaching process. Tytler and Prain [27–29] describe the importance of *transduction* in science teaching and learning, referring to the process where the meaning of one representation or semiotic resource (e.g., speech) is transduced to and re-articulated in another representation (e.g., image). We see this as also being applicable to learning about AR and SD. They propose, and we agree, that transduction in science learning involves creative reasoning enabled by cognitive and semiotic resources. They discuss the role of the teacher in guiding students to link, confirm, and expand meanings across representations, which is fundamental for students to learn concepts and processes in science. Transduction here refers to the process where children experience meaning from a specific content based on the experience of several different representations of that content that teachers help them link. Consequently, reasoning and inference are based on similarities and analogical transfer from the observed phenomenon to cause (i.e., the formulation of hypotheses of cause). This reasoning about why phenomena are perceived as they are can be seen as related to abductive reasoning [30], which begins with observations and proceeds to formulate possible explanations. Different representations in early-year science teaching convey different aspects of science content, hence, increasing the variation and opportunities for children to experience the teaching content [7,25,31].

2. Aim and Research Questions

The aim of this study was to explore how two experienced preschool teachers described their first experiences of the thematic teaching of AR and SD, with a special focus on place-based education. The research questions guiding the analysis were:

- How do preschool teachers describe thematic teaching including AR and SD?
- What is the role of place and transduction in the teaching and learning process?

3. Method

This was an exploratory case study that focused on work in two preschools, with the same preschool principal, in a small town in the southern part of Sweden. The preschools aim to develop work with sustainable development and digital technology, and therefore applied for and received a grant for an innovation project involving AR and sustainable development. Work with the sustainable development goals (SDGs) was ongoing in both preschools, but AR was a new area for the pedagogical staff. In the project, two preschool teachers (30 and 5 years teaching experience, respectively), one at each preschool, had initial training regarding AR and possible applications for preschool children. The preschool teachers next explored the applications together with their respective child groups of 4–5 year-olds (22 children in one preschool and 18 children in the other). The children participated in smaller groups in thematic teaching activities of AR and ESD during a semester. The children had no prior experience with AR applications. We chose to analyse the descriptions of these two experienced preschool teachers of their attempts at thematic teaching including AR and ESD in an explorative case study to develop knowledge of descriptive aspects of such pioneering work.

The researchers collected and analysed the preschool teachers' pedagogical planning documents and their final written report on the project. The content in these documents served as a foundation for a follow-up semi-structured interview conducted with the two preschool teachers by one of the researchers. The interview was audio-recorded and transcribed in full. A conventional content analysis [32] was conducted separately by the two researchers, who then met, discussed the codes, compared their analyses, and discussed tentative categories. In the next step, the categories were finalised and described as *AR + ESD: Thematic teaching*; *AR + ESD: Children's agency*; *AR + ESD: Teacher perspective*, and *AR: What is real and what is not?* In a subsequent step of the analysis, these categories were analysed and discussed by the researchers in relation to the concepts place and transduction. From the triangulation of the three data resources (i.e., planning documents, final written report, and interview), consistency was revealed in the preschool teachers' expressed experience during and after the project. The interview thereby confirmed and deepened the researchers' understanding of the content in the planning documents and in the final written report.

Ethical considerations adhere to recommendations by the Swedish Research Council [33]. In this study, this included written consent where the researchers informed the participants about voluntary participation, that the participants had the right to cancel their participation at any time, and that the participants and preschools would be given pseudonyms in the data when the study was reported on. The pseudonyms for the two teachers were Jennifer and Angelica.

4. Results

In the following, the two preschool teachers' descriptions of their teaching with AR and SD are presented under headings representing the identified categories.

4.1. AR and ESD: Thematic Teaching

In the two preschools, as in the rest of the municipality they are both part of, digitalisation and SD had been determined as prioritised areas of development. In their innovation project, the preschool teachers decided to combine the teaching of SD, in terms of the SDGs, and AR. They identified that the two content areas had a point of intersection where they both offered learning regarding problem solving, critical thinking, and communication. A content area can be described in terms of the didactic question 'what', while the teaching arrangements about the same can be described as the 'how' of the teaching [34]. The preschools both had previous experience of education for SD (ESD), but AR was a new and untried content area. One preschool teacher from each preschool was designated as the leader for the innovation project, and following an AR workshop, they started to plan the thematic work. When describing their integration of SD and AR in teaching, they concluded that they and the children had to start with learning AR as the first content area (i.e., a first 'what') before moving on to including SD, the second 'what' (i.e., a multidisciplinary approach). When SD was included and coupled with AR, AR could be described as going from a 'what' to a 'how' in the teaching, that is, AR then became a tool for learning about SD. The preschool teachers reasoned about this:

> Because if we hadn't had AR as the 'what' from the beginning, then it might had become the 'what' in the next period, when the 'what' was supposed to be SD. Then their [the children's] focus perhaps had ended up on "Oh, what's this? We have to explore this further." And then you lose the aim. So, I mean it could turn into an obstacle, if they don't have any previous knowledge about the AR technology. If you want to use it as a method, or a 'how' for a 'what', then it could be an obstacle because they are more captured by the technology itself than. . . (Angelica)

Children's fascination with tools is not unique to digital tools. When preschool teachers plan for scientific inquiry, it has been proposed that they introduce tools such as loupes, magnifiers, etc. to children first. Otherwise, the tools might be more interesting than the tree or insects the preschool teachers had planned to be the object of learning [34] in the teaching. However, based on our previous studies [12,31], our experience is that digital tools are especially interesting to many children. Furthermore, even though a transdisciplinary approach to thematic teaching is considered more advanced, with its starting point in real-life problems that integrate several contents, we see here that a multidisciplinary approach is favourable when one content functions as a tool in supporting learning about another content. Treating AR as a 'what' before transforming it to a 'how' is therefore seen to be a fruitful didactic strategy for the children's transduction of meaning in this teaching situation.

In their teaching of the SDGs, the preschool teachers decided to start with SDG6 (Clean water and sanitation) and SDG14 (Life below water). The reason behind their choice was that these goals relate to each other, and they were deemed concrete enough for the children to comprehend. During the activities, the preschool teachers and children visited a place close to each preschool, a pond and a creek, respectively. During the teaching, the children explored water from different sources and purified water. In the multidisciplinary approach, the children were also given opportunities to expand their learning to include more SDGs and their characteristic symbols, present in pictures on walls and tables in the preschools. The preschool teachers described how the children next started to identify that a place could be connected to a specific SDG, resulting in the preschool teachers taking walks or cycling around in the neighbourhood in 'hunts' for SDGs:

> They started to understand that it's the actions you do that can be connected to a SDG. So when we were out cycling we stopped perhaps at ICA [a local store] and then someone said "There's a goal!" Yes, what goal is that? "Zero hunger, because there's food. When we eat we're not hungry anymore." For example. (Angelica)

The children took photographs of the places they associated with a SDG and used an AR application to place the symbol of the corresponding SDG in the picture. The preschool teachers' statements on this are examples of transduction, where the meaning of one representation, the SDG, is transduced to another representation (e.g., the photo of the local food store representing 'Zero hunger'). Through their thematic teaching, the preschool teachers created prerequisites and links for the children's transduction of meaning between different representations. The AR application made it possible for the children to superimpose the SDG symbol on the photograph, thus augmenting the representation of reality.

In accordance with the preschool teachers' planned teaching, the children recreated their experience from a visit to the local recycling centre by building and representing the recycling centre in recycling material. This quickly escalated, and the children had their own ideas about more local places to represent from their experiences during their walks and bicycle tours:

> First the thought was that we should build a recycling centre of recycling material and when we had built it the children thought "but where is the water treatment plant?". So we had to build the treatment plant and then our pond and then all the places we visited. (Angelica)

The local places represented by the children were marked with associated SDGs (see Figure 1). Their ambitious representation of their small town led to an exhibition in the town library. Through the teaching process, with walks/bicycle tours in the neighbourhood and the subsequent reconstruction leading up to the library exhibition, the children's understanding was transduced between different representations of SDGs, places, and AR productions. Furthermore, place expanded on two levels during the thematic project as a result of the children's own ideas, partly in the number of places physically visited by the children, and partly in the number of representations in their recreation in recycling materials.

(**a**) (**b**) (**c**)

Figure 1. SDG 3, 15, and 7 represented in the children's recreation of local places they visited with their preschool teachers. (**a**) A local playground representing wellbeing; (**b**) insect hotels representing biodiversity; (**c**) solar panels representing clean energy.

4.2. AR and ESD: Children's Agency

The teaching described above can also be reasoned in terms of the children's agency. In thematic teaching, the children's perspectives, in the joint process of formulating themes based on the children's participation and agency, are paramount [16]. Agency is often thought of as the capacity of individuals to influence and steer their own lives, with a view of agency as an internal ability. Another way of viewing agency is as something a group of individuals achieve together in transactions rather than something they possess [35]. Here, we did not want to polarise between the two views and instead defined agency in the sense of children, individuals, or as a group, being able to take action and pursue new lines of exploration and interaction in their everyday lives and places.

From the start, the children's own ideas were important for the preschool teachers to consider for them to be able to offer learning about problem solving, critical thinking, and communication. In one of the preschools, a nearby creek was chosen as a place for teaching, based on the children's engagement:

> And then we had the local environment, we should include that too. And then we had [the creek's name] nearby where the children already. . . "It's dirty!" because they are already little climate activists. "Oh, there's garbage!" because you can't take a walk without them collecting. (Jennifer)

During their walks and bicycle tours, the children and the preschool teachers interacted in different ways with their neighbourhood. For example, they visited the local food store to discuss what fish was most sustainable, they visited the library where a child commented, "This is SDG4! [Quality education]", and they reasoned about the garbage in the creek. A child suggested that they should put a sign on the bridge over the creek, stating that it was not allowed to throw garbage in the water. This initiated a discussion of whether it was allowed for anyone to put up signs. The preschool teacher and children decided to write a letter to the municipality and ask them to put up a sign, and the municipality responded by doing so (Figure 2).

Figure 2. A sign with the Swedish text "Släng inte skräp i ån. Tack.", in English "Do not throw garbage in the creek. Thank you." The sign was put up after the children wrote a letter to the municipality asking for one.

The children's engagement in their local places could be connected to the slogan "Think globally, act locally", attributed to Geddes [36] and referring to the fact that people should consider sustainable development and take action in their everyday lives for the sake of our shared planet. Additionally, research has shown that children need to develop a positive attitude and care for their own local place, in order for them to later care about the environment on a larger scale [26,37,38]. Sobel criticises aiming for too abstract concepts with children and instead emphasises pedagogical strategies that relate to them. In her words, "what's important is that children have an opportunity to bond with the natural world, to learn to love it before being asked to heal its wounds" [38] (p. 10).

The project is thus an example of place-based learning where the children's understanding and meaning-making are transduced, through their agency, between different places and representations. Furthermore, democratic processes in society are included in the teaching when children learn that taking action and writing to the municipality has an effect, and that their exhibition in the library can be viewed by other citizens. Their experiences have the potential to make them action-competent citizens in the future.

Other examples of children's interests were described by the preschool teachers in situations outside the planned teaching. If one child spontaneously took a computer tablet to "do AR", other children immediately gathered around the child to give tips and to help out:

> In the spontaneous teaching, it was like a meeting place, the children were there and gave each other tips and ideas, "but if you try like that, if you do like that." "I'm placing myself here, can I reach it now or do I need to sit down?". Then they started to cooperate. (Angelica)

There were also examples of how the use of the AR-applications strengthened the status of individual children:

> You can as a teacher deliberately choose to give this [the computer tablet] to him who maybe doesn't have the highest status in the group. Then it's him who gets to take photos and film in this free. Then he gets four-five around him immediately who are super interested in him. So he gets to take place and control it a bit. And then he doesn't think about that it's him controlling. (Jennifer)

Here, the preschool teacher talked about using the computer tablet and the AR applications as a tool to lift a child and let that child take the lead. This example is interesting, given the implication of AR use as a tool for inclusion. It also reflects a result in one of our previous studies [39], where a child who had difficulties playing with other children found it easy when the play involved programming a robot. This indicates a role for digital tools in social inclusion and social sustainable development.

The preschool teachers said that when the children chose to use AR applications outside of the planned teaching, it often involved their own drawings. These were often made in the application Sketches School, where pictures also can be downloaded, prompting discussions among the children and preschool teachers about which pictures you are allowed to download. Children also played with the colourful representations of the SDGs that had been added in the AR-maker application and interacted with the preschool teachers while doing so:

> And then it was kind of fun if I was sitting there because then he could put one [symbol of SDG] on the head and then I was supposed to hold my hand like this [holds out her arm with her palm facing upwards] because then he could put one there [in the hand]. So they became good at it and the symbols and understood so they could do it themselves later. (Jennifer)

The preschool teachers also described how the children were engaged in exploring different orientations and distances in the computer tablet and how this affected the digital scene visible in the AR-maker. They often asked a friend to also place him- or herself in the scene.

The preschool teachers viewed their use of the children's thoughts and ideas as a crucial part of the children's learning process. In one of the preschool teachers' words, "they have been owners of their own learning, I would say." The preschool teachers also reflected on the children's awareness of their own learning:

> I wrote in the analysis that "the fact that digital competence is integrated in the teaching gives the children a computational thinking and makes them seek knowledge and we give the children a basic critical approach through the AR technology. Then the children become aware of their own learning identity. How they view themselves as a learning individual. We believe we achieve this by creating teaching in different variations." (Jennifer)

The role of varied teaching is further elaborated on below, in relation to the teacher perspective.

4.3. AR and ESD: Teacher Perspective

The preschool teachers reasoned about the project in relation to their professional role and underlined the importance of having a colleague to discuss ideas with. They also stressed structural prerequisites such as substitutes and time to learn AR:

> That this has succeeded. . . The success factor is that we have had time, we have split it into small parts, we have had small teaching groups, we have also had

> the time outside to go in and take some children and try out. You don't have that possibility when you have a full group of children. (Jennifer)

Several aspects of teaching the children were also discussed. The preschool teachers provided examples of how AR was also integrated in their daily work outside of the project with the SDGs. When baking a cake for a parental meeting, some children baked while other children took pictures of the process for use in AR applications. Here, the preschool teachers talked about the value of daring to try and to fail when learning AR:

> Well, not safe really but "let's try this way then". If it doesn't go right, well, then there won't be a film. But there will be apple pie. (Jennifer)

The preschool teachers also stated the importance of variation when teaching children, and provided examples of how some children who were normally quiet during a traditional whole-group gathering started expressing their thoughts during activities when they were painting SDGs. Other children became more active when singing songs related to the SDGs, while other children preferred talking while doing the experiments. The varied teaching with possible support from peers and teachers can be seen as crucial for the transduction of meaning from different representations.

Another aspect of AR in teaching is, according to the preschool teachers, the use of the applications in a conscious way. The preschool teachers explained how they had constricted the children's use of computer tablets to some days being only about specific AR applications such as Tayasui Sketches School™ or AR Makr™. Therefore, the project has improved this conscious use among the preschool teachers in the two preschools:

> And that has also derived from the project extra I think, that we now in the staff will emphasize developing a conscious approach to how we use the digital technology in the child groups. To sort of not just place the iPad there, but instead "why are we doing it, are they going to play?", really think through what obstacles, what possibilities are there with this technology? Does it contribute to your aim or doesn't it? Does it counteract it or aid it? I think that has got a little extra boost now that we see that we have used the technology in a conscious way like we have done here, then it can also contribute to an enhanced learning in the children. (Angelica)

The preschool teachers described different challenges in their teaching. One of them involved not taking over when instructing the children about the applications:

> Anna: And then you should "and now you touch the white circle at the far end of the screen" and before they find it (laughter). They learn by doing themselves but I found this to be a challenge.
>
> Jennifer: Yes it was.
>
> Anna: To not accidently do like. . . (grabs the computer tablet to illustrate taking over)
>
> Jennifer: Yes, it was. And then we have opted out on some apps because we thought they were too difficult and we couldn't even teach it to the children.

The preschool teachers also identified a challenge in the spontaneous teaching of SDGs at local places. Here, they did not always have the content knowledge required to answer the children's curious questions:

> It has been difficult if you all of a sudden have come upon a goal that you don't know a lot about. We're cycling on an excursion, comes to [local factory]. Yes, what goal is this? What goal can be connected..? (Angelica)

Another challenge lies in transferring their new knowledge of AR to their colleagues who do not have the same time to learn the applications that the two preschool teachers had during the project. The teaching of the SDGs has been more 'alive' in the two preschools compared to the teaching of the newer content AR. The preschool teachers' wish is that use of the AR technology in teaching will be as natural as greenscreen or programming have become in preschools. They acknowledge and reason that incorporating new technology takes time:

> Exactly, they haven't had the time. Then it's also about you as a person. Some goes "Ah, let's try. What's the worst thing that could happen?", while some "No, I need to know this before I. . ." That is, want to control it before you take it out to the child group. We are also different there. (Angelica)

The above example illustrates how challenging teaching and building on the transduction of meaning across different representations can also be for teachers, who need to think through, plan, generate, or spontaneously use them.

Yet another challenge for the preschool teachers concerned the children's continued learning in school and later on in life—the 'being' or 'becoming' perspectives, here and now, or in the future [40,41]. A becoming perspective can be identified in the following statement:

> I was a bit frustrated in that, mm, now we work with this. AR technology, sustainable development. Then I will leave them to school, will the school continue on this? (Jennifer)

Finally, the preschool teachers described a challenge in discussions with the children about what was real and not real. This is further elaborated on in the next section on AR technology.

4.4. AR: What Is Real and What Is Not?

The introduction of AR strategies inherently introduces issues of abstractions, abstract thinking, representations, and metaphors. The children introduced questions concerning authenticity and about what was 'real' and not, for instance, in comparing photos from 'real' (local) places or drawings they had made themselves to photos of unknown sites downloaded from the Internet. This is something that we believe highlights the importance of place and materials from the children's everyday lives.

> Researcher: It's also exciting this with what is real and what is. . .
>
> Jennifer: Yes, and it was often expressed, 'but that's not for real. That's AR' they said.

Initially, the children struggled to understand and were not able to transduce or make sense of the additional information from the AR. It could sometimes be confusing for them that an object in the AR application could appear against a physical background, seen through the camera lens in the computer tablet. The preschool teachers described how the children's physical paper drawings aided the discussion. When the children were given the opportunity to draw paintings on paper, photograph these paintings, and add the photos to the AR application, they obtained an understanding of the physical versus digital object. This points to an important role for physical material, generated by the children themselves, to help them transduce meaning between physical and digital representations.

> Mm, but I thought it became clearer to the children, this with reality and not, when they created their own objects and placed. Because if we took ready-made pictures from the internet and placed, then it was still just a picture. And you keep pictures on an iPad, that's not unusual. But to be able to take something you yourself has made, that is not a digital picture but to make it into a digital picture that you can place. . . (Angelica)

Several examples were raised where the preschool teachers experienced that the AR technology and use of the apps were helping the children to transduce meaning between different representations, for instance, by making the abstract notion of water content in our bodies more accessible.

> Then we used AR because we talked about that it's really important that we drink, it's really important to get water. And a human being has a lot of water

> in his body. Well, it's perhaps a bit abstract but with AR we could make a body that we drew, that we filled to 60–70 percent with water. Then the children could place themselves behind that body and get to see on their own body that 'But about up to here on my body, I have water'. So it became a bit more concrete. (Angelica)

The children also added extra representation, making it clear to the preschool teachers that they were helped by and enjoyed the opportunities to transduce from multiple inputs.

> After we had made the AR-body, then two children took out. . . We have cubes in different colours with lamps. Then they took the blue lamp, then they started building it like a tower. And then they placed themselves behind it, "I have this much water in my body." So I thought the AR technology contributed to an increased understanding for the children in that situation.

The preschool teachers were adamant that functionality without technical issues was very important for the children's learning and enthusiasm. However, they mostly talked about the problems that they had had themselves in planning and preparing for the activities with the children.

> Yes, it has messed up. When it comes to the AR technology. . . It's been a challenge I think, to use, especially these digital scenes. To make it good. Because even if I make a digital scene, then I save it. Then, when I should open it again it doesn't bring out the same. . . Even if I scan the same place, the scanning won't be the same. All of a sudden the pictures end up in different places or it changes the angle on it. So it's not easy to reuse one's digital scenes that one created for example. There are question marks like that that I find a bit difficult. (Angelica)

Sometimes the children were not happy about the limitation introduced by the technique, for instance, in terms of drawing with the digital pen. They felt that it was difficult to achieve thin lines, and the pen did not also make the correct sound when moved over the tablet.

> Yes, and then they were just irritated and it ended with "no, I give up because it's not how I want it." They wanted to be able to make thin lines and it's not as easy on an iPad as it perhaps is to do it on a paper. My interpretation is that they thought they should be able to draw the way they can in reality. (Angelica)

The preschool teachers also let on that technical development is very rapid, and that it is difficult to keep up. There were examples where they realised that things they had learnt to do were no longer valid or necessary.

> And then it was also, he taught us a lot on Keynote. I mean to remove the background to insert your object, floating. But all of a sudden iPhone 16 came with that. You just hold. . . You don't need Keynote for that anymore. (Jennifer)

Finally, the preschool teachers reasoned about what reality had been augmented through the project.

> Researcher: The question is. . . What is it that has been augmented concretely? What reality has been augmented?
>
> Angelica: I would probably say the sustainable development goals' presence in our environments, in our everyday lives. That it's easy to sit here and talk about sustainable energy or, but through being able to put these cubes in different places, that understanding has deepened. Or become concrete, or how it can be expressed. It has enhanced the reality, if one can put it like that?

Children's excursions with the computer tablet around their local neighbourhood enabled them to identify SDGs and transduce their understanding from the real-world context to a digital representation of that place.

5. Discussion and Conclusions

In the following, the two research questions guiding the analysis are addressed intertwined, ascertaining coherence between the preschool teachers' statement and the theoretical framework. Early childhood education is usually situated within 'a place', whether this place has been called a preschool, kindergarten, or nursery [42]. According to the preschool teachers in the present study, the preschool children gained a greater understanding of how local places around them were related to different SDGs. Sobel describes place-based education as the process of using the local community and environment as a starting point to teach different subjects in curriculums. She emphasises hands-on, real-world learning experiences due to the ability of these educational strategies to scaffold the students' academic achievements, appreciation for the natural world, and their heightened commitment to function as active, contributing citizens [43]. Grünewald describes how socially constructed places such as giant shopping malls, urban streets, and schools tend to be taken for granted [22]. Becoming aware of social places as human products requires conscious reflection about how we influence these places. Furthermore, the preschool teachers in this study described how the children's understanding was enhanced by the use of AR technology. The children transduced their knowledge and meaning of the SDGs between representations in the physical world such as local places, paper drawings and recycled materials and the digital world with the colourful SDG symbols in AR applications. The children's new awareness of how local places through AR applications can be connected to specific SDGs and their actions when, for example, writing to the municipalities asking for a sign against garbage, could be viewed as important steps for them to become what Grünewald describes as 'place makers' [22] (2003a). Even though a transdisciplinary approach to thematic teaching can be desirable, the teachers set out with an interdisciplinary approach, expecting to integrate AR and ESD. However, they ended up with a more multidisciplinary approach where AR was treated separately and in advance. It was seen that in order to be a useful tool in the ESD learning process, some skills in using AR applications were a prerequisite. The preschool teachers' experiences from the use of AR in preschool settings has, to our knowledge, not been reported on earlier.

Furthermore, Grünewald criticises traditional schooling for their lack of place-based education [26], and the results from this study point to important possibilities for place-based education in preschools. With a less formalised day compared to school, Swedish preschool teachers operate without a classroom, have opportunities to explore local places with their child groups, and to work with these places thematically. At the same time, different preschools around the world have different prerequisites to do so. Heavy traffic or too few staff members are just some of the risk factors that need to be considered. Furthermore, many educators emphasise tragedy and catastrophes in ESD. Sobel responds by stressing the importance of reclaiming the heart in place-based education, where experiences are created for people to connect with places close to home [38]. This more positive take on ESD is believed by us and others to be especially important when working with young children.

To conclude, the results of this study point to four key points in the thematic teaching of AR and SD in preschools:

- There is a value in learning AR first, before using it as a tool for ESD. An initial multidisciplinary approach could be fruitful in thematic teaching that involves digital content previously unknown to the children.
- The children's own ideas, self-generated images, and familiar places are important motivational factors when learning AR and ESD and their agency should be a crucial part of the teaching of the same.
- Teachers need structural prerequisites to be able to prepare and develop knowledge and consciousness about the teaching of AR and ESD.
- A varied teaching approach is crucial for children in a group to be able to link and transduce the meaning of ESD through multiple representations.

- Children's linking and transducing of different representations, especially in terms of what is real and not, requires active teaching.
- Pictures of the children's own physical creations such as drawings may aid in the understanding of what is real and not, in the AR application.

The aim of planned follow-up studies is to investigate the interactions of children and preschool teachers during teaching activities involving AR and ESD.

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References

1. Albayrak, S.; Yilmaz, R.M. An Investigation of Pre-School Children's Interactions with Augmented Reality Applications. *Int. J. Hum.–Comput. Interact.* **2022**, *38*, 165–184. [CrossRef]
2. Aydoğdu, F. Augmented reality for preschool children: An experience with educational content. *Br. J. Educ. Technol.* **2021**, *53*, 326–348. [CrossRef]
3. Swedish National Agency for Education. *Curriculum for the Preschool Lpfö 18*; Swedish National Agency for Education: Solna, Sweden, 2019.
4. Brundtland, G.H. *Our Common Future*; World Commission on Environment and Development: London, UK, 1987.
5. Ärlemalm Hagsér, E.; Pramling Samuelsson, I. "Business as Usual"? Or Transformative and Transactive Teaching Leading towards the Agenda 2030 Goals in Swedish Early Childhood Education. *Int. J. Early Childhood Environ. Educ.* **2021**, *9*, 94–111.
6. UNESCO. *Education for Sustainable Development, A Roadmap*; The United Nations Educational, Scientific and Cultural Organization: Paris, France, 2020.
7. Fridberg, M.; Jonsson, A.; Redfors, A.; Thulin, S. The role of intermediary objects of learning in early years chemistry and physics. *Early Child. Educ. J.* **2020**, *48*, 585–595. [CrossRef]
8. Fleer, M.; Pramling, N. *A Cultural-Historical Study of Children Learning Science*; Springer: Dordrecht, The Netherlands, 2015.
9. Larsson, J. Children's encounters with friction as understood as a phenomenon of emerging science and as "opportunities for learning". *J. Research in Childhood Educ.* **2013**, *27*, 377–392. [CrossRef]
10. Thulin, S. *Lärares Tal och Barns Nyfikenhet: Kommunikation om Naturvetenskapliga Innehåll i Förskolan*; [Teacher Talk and Children's Queries: Communication about Natural Science in Early Childhood Education.]; Acta Universitatis Gothoburgensis: Gothenburg, Sweden, 2011.
11. Fleer, M. Supporting Scientific Conceptual Consciousness or Learning in 'a Roundabout Way' in Play-based Contexts. *Int. J. Sci. Educ.* **2009**, *31*, 1069–1089. [CrossRef]
12. Fridberg, M.; Jonsson, A.; Redfors, A.; Thulin, S. Teaching Chemistry and Physics in Preschool—A Matter of Establishing Intersubjectivity. *Int. J. Sci. Educ.* **2019**, *41*, 2542–2556. [CrossRef]
13. Spektor-Levy, O.; Baruch, Y.K.; Mevarech, Z. Science and Scientific Curiosity in Pre-school—The Teacher's Point of View. *Int. J. Sci. Educ.* **2013**, *35*, 2226–2253. [CrossRef]
14. Thulin, S.; Redfors, A. Student Preschool Teachers' Experiences of Science and its Role in Preschool. *Early Child. Educ. J.* **2017**, *45*, 509–520. [CrossRef]
15. Doverborg, E.; Pramling, I. *Temaarbete. Lärarens Metodik och Barns Förståelse*; [Working with themes. Teachers' methods and children's understanding]; Utbildningsförlaget: Stockholm, Sweden, 1988.
16. Jonsson, A.; Redfors, A.; Fridberg, M. Child perspective and children's perspectives in student preschool teachers' talk about thematic teaching including science in preschool. 2024, *submitted manuscript*.
17. Pramling, I. Learning about "the shop": An approach to learning in preschool. *Early Child. Res. Q.* **1991**, *6*, 151–166. [CrossRef]

18. Ortiz-Revilla, J.; Greca, I.M.; Arriassecq, I. A Theoretical Framework for Integrated STEM Education. *Sci. Educ.* **2022**, *31*, 383–404. [CrossRef]
19. English, L.D. STEM education K-12: Perspectives on integration. *Int. J. STEM Educ.* **2016**, *3*, 1–8. [CrossRef]
20. Frodeman, R.; Klein, J.T.; Pacheco, R. (Eds.) *The Oxford Handbook of Interdisciplinarity*, 2nd ed.; Oxford University Press: Oxford, UK, 2017.
21. Geertz, C. Afterword. In *Senses of Place*; Feld, S., Basso, K., Eds.; School of American Research Press: Santa Fe, NM, USA, 1996; pp. 259–262.
22. Grünewald, D. Foundations of Place: A Multidisciplinary Framework for Place-Conscious Education. *Am. Educ. Res. J.* **2003**, *40*, 619–654. [CrossRef]
23. Casey, E. Body, Self and Landscape: A Geophilosophical Enquiry into the Place World. In *Textures of Places; Exploring Humanist Geographies*; Adams, P., Hoelscher, S., Till, K.E., Eds.; University of Minnesota: Minneapolis, MN, USA, 2001.
24. Scott, I. Rebuilding a sense of place. *Taproot* **2002**, *13*, 3–5.
25. Redfors, A.; Fridberg, M.; Jonsson, A.; Thulin, S. Early Years Physics Teaching of Abstract Phenomena in Preschool – Supported by Children's Production of Tablet Videos. *Educ. Sci.* **2022**, *12*, 427. [CrossRef]
26. Grünewald, D. The Best of Both Worlds: A Critical Pedagogy of Place. *Educ. Res.* **2003**, *32*, 3–12. [CrossRef]
27. Prain, V.; Tytler, R. Theorising learning in science through integrating multimodal representations. *Res. Sci. Educ.* **2022**, *52*, 805–817. [CrossRef]
28. Tytler, R.; Prain, V. Supporting student transduction of meanings across modes in primary school astronomy. *Front. Commun.* **2022**, *7*, 863591. [CrossRef]
29. Prain, V.; Tytler, R. Guiding student transduction in elementary school astronomy. *J. Res. Sci. Teach.* **2024**, *61*, 1181–1205. [CrossRef]
30. Adúriz-Bravo, A.; Sans Pinillos, A. Abduction as a mode of inference in science education. *Sci. Educ.* **2023**, *32*, 993–1020. [CrossRef]
31. Fridberg, M.; Thulin, S.; Redfors, A. Preschool children's Communication during Collaborative Learning of Water Phases Scaffolded by Tablets. *Res. Sci. Educ.* **2018**, *48*, 1007–1026. [CrossRef]
32. Hsieh, H.F.; Shannon, S.E. Three approaches to qualitative content analysis. *Qual. Health Res.* **2005**, *15*, 1277–1288. [CrossRef]
33. Swedish Research Council. *Good Research Practice*; Swedish Research Council: Stockholm, Sweden, 2017.
34. Marton, F. *Necessary Conditions of Learning*; Routledge: London, UK, 2014.
35. Caiman, C.; Lundegård, I. Pre-school children's agency in learning for sustainable development. *Environ. Educ. Res.* **2014**, *20*, 437–459. [CrossRef]
36. Geddes, P. *Cities in Evolution*; Williams: London, UK, 1915.
37. Beery, T.H.; Lekies, K.S. Childhood collecting in nature: Quality experience in important places. *Child. Geogr.* **2019**, *17*, 118–131. [CrossRef]
38. Sobel, D. *Beyond Ecophobia: Reclaiming the Heart in Nature Education*; The Orion Society and The Myrin Institute: Great Barrington, MA, USA, 1996.
39. Fridberg, M.; Redfors, A.; Greca, I.M.; Terceño, E.M.G. Spanish and Swedish teachers' perspective of teaching STEM and robotics in preschool—Results from the botSTEM project. *Int. J. Technol. Des. Educ.* **2023**, *33*, 1–21. [CrossRef]
40. Halldén, G. Barnperspektiv som ideologiskt eller metodologiskt begrepp. [Child perspectives as ideological or methodological concept]. *Pedagog. Forsk. I Sver.* **2003**, *8*, 12–23.
41. Qvortrup, J.; Bardy, M.; Sgritta, G.; Wintersberger, H. (Eds.) *Childhood Matters: Social Theory, Practice and Politics*; Averybury: Aldershot, UK, 1994.
42. Boyd, D. Utilising place-based learning through local contexts to develop agents of change in Early Childhood Education for Sustainability. *Int. J. Prim. Elem. Early Years Educ.* **2019**, *47*, 983–997. [CrossRef]
43. Sobel, D. *Place-Based Education: Connecting Classrooms and Communities*; Orion Society: Barrington, MA, USA, 2004.

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Article

Young Children's Self-Regulated Learning Benefited from a Metacognition-Driven Science Education Intervention for Early Childhood Teachers

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Abstract: The two goals of this study are to examine the impact of an early childhood teacher's metacognition-driven, place-based science teaching professional development (PD) intervention and to explore the association between science teaching and environment quality and children's self-regulated learning. A total of 110 children (Mage = 60 months) and 20 teachers from preschools and kindergartens in rural regions of Idaho, U.S., participated in this mixed-methods study between August 2022 and May 2023. Children's and teachers' pre-test and post-test data were collected using validated observation tools, surveys, and reflection journals. The results from repeated measures ANOVA and linear mixed regression show that there were statistically significant increases in children's self-regulated learning scores and teachers' science teaching efficacy and metacognitive knowledge, but not metacognitive regulation skill scores post-PD. Thematic analysis revealed evidence about children's learning interests and inquiry skills, and that science activities supported children's learning in other subjects and developmental domains (e.g., literacy, mathematics, and social-emotional skills). Our results indicate the potential for supporting young children's self-regulated learning by training teachers to implement a developmentally appropriate, hands-on science curriculum that focuses on reflective thinking and a holistic understanding of science concepts and process skills.

Keywords: early childhood; science education; self-regulated learning; metacognition; professional development

1. Introduction

1.1. Self-Regulated Learning

In an age of information technology characterized by an abundance of rapidly evolving knowledge, cultivating self-regulated learners is becoming increasingly important [1]. Self-regulated learning (SRL) is an umbrella term that includes cognitive, metacognitive, social–emotional, and motivational aspects of learning [2,3]. Self-regulated learners have a proactive and adaptive approach to learning, which equips them with the skills and mindset to navigate complex education settings and beyond [4]. Self-regulated learners master their own learning by setting goals, applying effective learning strategies, and pressing on in the face of challenges [2]. Research has linked self-regulated learning to school outcomes from childhood to adolescence across several subject areas [5,6].

Early childhood is a prime time window for fostering SRL, given young children's rapidly developing cognitive faculties [7,8]. Teachers' instructional support and learning environment play an important role in nurturing children's SRL [9]. In particular, teachers' support during science inquiry learning activities may have great potential to support children's SRL [10–12], given that the inquiry learning cycle (i.e., ask, investigate, create, discuss, reflect) mirrors the SRL model [13,14]. Therefore, this present study aims to examine the effect of an early science education intervention on children's SRL.

1.2. Young Children's SRL and Metacognition

Zimmerman's theoretical model of SRL [15], although widely adopted, does not account for young children's cognitive limitations [16]. Preschool- and kindergarten-aged children's SRL is still developing; as a result, they may have challenges in effectively regulating their learning processes [16]. Some of these challenges include limited cognitive control, difficulty with goal setting, and limited understanding of one's cognitive processes, which could be due to young children's immature executive functioning (i.e., a collage of cognitive abilities such as working memory, cognitive flexibility, and inhibitory control [17]). Therefore, this study adopted a theoretical framing of SRL more suited for young children, as proposed by Bronson and Bronson [18], and Whitebread and colleagues [19]. This framework includes four categories of SRL: emotional (e.g., regulate one's emotions, especially when facing challenges), prosocial (e.g., collaborate with others and being aware of others' feelings), cognitive (e.g., aware of oneself and strategies), and motivational (e.g., initiative and task persistence).

A defining characteristic of SRL is the ability to regulate one's own cognition and motivation during a learning episode [15], and the prerequisite for SRL is metacognition [20]. Metacognition is a cognitive function that involves being aware of and controlling one's mental processes [21,22]. Metacognition researchers agree on the three core components of metacognition [22–25]: metacognitive knowledge (i.e., knowledge about the person, task, and strategies), monitoring (i.e., gauging one's cognition during a goal-oriented task), and control (i.e., using information gathered during metacognitive monitoring to adjust subsequent actions to facilitate problem solving).

Whether and to what extent young children (e.g., age 3–5 years) can think metacognitively is debatable in the fields of education and psychology [26–29]. Early metacognition researchers claim that metacognition does not emerge until middle childhood [29]. This notion is partly due to the measurement limitation—many relied heavily on the participants' language ability to report their mental processes, which young children lack [9,30]. More recent research has used developmentally appropriate methods to assess young children's metacognition, such as play-based observation tools [19,23], interviews [31], and simple computer tasks [32]. In general, researchers found that young children could reflect on their own thinking; however, they tend to overestimate their task performance and struggle with calibrating their decision making based on cognitive monitoring [33]. These results echoed recent neuroscience findings: the neural correlates of metacognition seem to reside in the anterior cingulate cortex—a brain region that connects the prefrontal cortex with the limbic system and plays an important role in motivation, decision making, and error monitoring but which is far from maturing during early childhood [34,35]. Therefore, adults' facilitation and enriched environments are necessary to leverage metacognition and SRL to promote young children's learning and development [36,37].

1.3. Foster Young Children's SRL

SRL can be improved through the direct teaching of learning strategies [38], interactions with others [37], and enriched learning environments [5]. Ample studies have examined effective SRL strategies that are teachable and applicable in education settings, such as setting learning goals, concept mapping, reciprocal teaching, and cognitive reflection [39–41]. Yet, the majority of these studies are conducted with older children and adults [42–44]; as a result, many SRL strategies do not apply to the early childhood age group (i.e., preschool- and kindergarten-aged children). Given young children's rapidly evolving mental capabilities, developmental appropriateness is the key when it comes to supporting their learning and development [16,45,46]. Some commonalities across studies on pedagogical practices that foster young children's SRL and metacognition are adults' dialogic support, modeling, and learning context [20,37,47].

1.3.1. Teachers as Agents and Learners of SRL

Teachers have a dual role in fostering children's SRL as agents and learners of SRL [48]. First, teachers operate as agents of SRL by providing instructional support to children. Research studies shed light on ways that early childhood teachers can support young children's SRL, such as directly teaching SRL strategies (e.g., setting learning goals and reflecting on learning experiences), scaffolding, promoting learners' autonomy, providing constructive feedback, and creating a learning environment that values explorations and collaboration [20,49]. These teaching strategies are linked to children's learning gain and growth in SRL [47]. However, much less empirical attention is paid to the teachers' second role as learners of SRL. To help children develop their SRL, teachers must first become competent self-regulated learners themselves [50]. The four SRL competence components are teachers' SRL knowledge, skills, self-efficacy, and motivation/value [48]. Purposeful training, such as teachers' preparation and professional development programs, is pivotal to enhancing teachers' SRL competence [51].

1.3.2. SRL and Early Science Learning

SRL can be supported by an array of subject domains in early childhood classrooms, such as literacy and mathematics [4,49]; however, we argue that early childhood science activities, with proper support from teachers, provide a prime context to foster young children's SRL. Children are born inquisitive and eager to learn through hands-on exploration [52,53]. Science learning activities capitalize on young children's innate curiosity, promote autonomy, and foster metacognitive thinking and problem-solving skills, all of which are essential components of SRL [54]. Additionally, with the absence of standardized testing, early childhood teachers have a higher degree of freedom to pursue science activities driven by children's interests as compared to their counterparts in higher grades, making science learning uniquely suited for early childhood education [55].

1.4. Science Learning in Early Childhood Classrooms

1.4.1. Science Learning Starts Early

Contrary to the notion that science only takes place in laboratories led by highly trained scientists, young children, as young as infants, possess rudimentary scientific reasoning skills [53,56,57]. In Walker and colleagues' study [57], 18–30-month-old children were capable of discovering the association between sounds and different buttons on a box through trial and error, indicating that very young children could detect patterns of conditional probability and exhibited a rudimentary form of causal reasoning. Indeed, young children possess some domain-general learning skills and are already "experts" in learning through experimentation—the core of scientific discoveries [58].

Science learning does not only start early; scientific exploration is also developmentally appropriate for supporting children's learning [59,60]. During preschool and kindergarten, children's symbolic thinking emerges, and abstract reasoning becomes more and more explicit [28]. This transformation is aided by adults' support and hands-on learning materials, which allow children to manipulate and experiment while engaging multiple senses [61]. Science activities often involve experiential learning, and it is through interacting with hands-on materials that young children form abstract understandings of a scientific concept from concrete representations [62].

1.4.2. Developmentally Appropriate Early Childhood Science Education

Research findings in neuroscience and cognitive and developmental psychology shed light on possible reasons that integrative science learning is developmentally appropriate for young children. Brains process information from different sensory modalities such as visual, audio, and tactile information in a coordinated manner [63]. Integrative learning, such as learning mathematics and language while engaging in hands-on science activities, stimulates various areas of the brain to generate a more comprehensive understanding of information [64,65]. This is especially important for young children, to whom experiential learning transforms concrete objects into abstract understanding [45,66]. Also, early childhood is a sensitive period in human development, where children's brains are constantly organizing synaptic connections in response to the environment and experiences (i.e., brain plasticity) [7]. Adults' support (e.g., asking open-ended questions, activating prior knowledge) is particularly important for early science learning because it can offset young children's cognitive limitations and boost science learning outcomes [46]. Therefore, providing young children with individualized support and environments enriched with science learning opportunities is crucial for their knowledge gain as well as for later development [67].

Early childhood science teaching traditions include various approaches aimed at introducing young children to scientific concepts and scientific process skills [50]. Examples of these traditions include outdoor exploration (i.e., observing and interacting with natural elements in the outdoors), hands-on experiments (i.e., allowing children to test their hypotheses by interacting with science materials), storytelling (i.e., learning science concepts in a narrative format), sensory learning (i.e., engaging children's senses during science exploration), child-led inquiry (i.e., giving children opportunities to ask questions and investigate), and integrative science learning (i.e., incorporating science in everyday activities like cooking and gardening) [68]. Overall, these traditions prioritize active engagement and children's curiosity, promote science concept learning, and foster a sense of appreciation for science [69].

Research studies on developmentally appropriate early childhood science education focus on understanding how young children develop general scientific skills, attitudes, and concepts in specific domains (e.g., weather and seasons; plants and animals; living and non-living things) [70]. There are several trends in current research on early childhood science education. There is a notable emphasis on integrating science learning with other subject areas such as technology, engineering, art, and mathematics (i.e., STEAM) in children's daily lives [71]. Moreover, early childhood science education seems to deviate from the traditional teacher-centered approach to child-centered approaches, such as problem-based learning and inquiry-based learning [61]. Family and community engagement are also recognized as a crucial component of early childhood science education [72].

1.4.3. Current State of Science Learning in Early Childhood Education Settings

Despite the multifaceted benefits of early science education, science is a much less emphasized subject area in early childhood education [62,71]. Research investigating early childhood teachers' instructional time allocations found that teachers spent much less time on science activities than on literacy, language, mathematics, and social study activities [73,74]. Relatedly, early childhood teachers' perceived confidence and capacity in teaching science is lower than in other subject areas, which may lead to fewer science learning opportunities in the classroom [73,75]. Previous research also indicates that some early childhood science activities are hands-on but not "minds-on"; in other words, teachers tend to pay more attention to the pragmatics of the science activity than how children can make sense of what is being performed [76,77]. Inquiry-based science learning activities, for example, require learners to propose predictions by drawing on existing knowledge and form conclusions by comparing hypotheses with evidence gathered during investigations [54]. The cognitive skills involved in inquiry based learning are still developing in preschool and kindergarten children [16], which may impede their ability to construct accurate understanding from inquiry learning activities [68]. Young children's cognitive limitations underline the importance of teachers' effective support during science learning activities via approaches such as questioning and activating prior knowledge [78]. However, early childhood teachers' science learning support seems to be sporadic rather than purposeful [79].

Researchers have identified several challenges that may have hindered early childhood teachers' capacity and willingness to conduct science activities, for instance, the lack of developmentally appropriate science pedagogical content knowledge [79], poor resources [80], and classroom management issues [81]. Further, many early childhood curricula and learning standards emphasize literacy and mathematics more than science [73], which can partially explain the unbalanced instructional attention [53]. Additionally, early childhood teachers tend to be anxious about conducting science activities because they doubt their ability to answer children's questions [82]. This issue indicates teachers' belief that they must have comprehensive knowledge about certain science topics in order to lead an activity [81]. However, teachers should adopt and model the mindset that science is a dynamic discovery process; a gap in their understanding is not embarrassing, rather, it affords an opportunity for learning with children [82].

1.5. Professional Development Programs

To nurture children's SRL using science activities, teachers must become competent self-regulated learners who possess the necessary knowledge and positive attitudes towards science [83]. Well-designed education interventions, such as teachers' PD programs, can help teachers become self-regulated learners [68,69]. It is important to note that not all PD programs are education interventions by default [84]. For a PD program to become an education intervention, it must have a purposeful education and research design, evidence-based activities, targeted areas of improvement, and empirical data that can support the effect of the PD program [85]. A recent meta-analysis on effective education intervention targeting children's SRL and metacognition indicates that contrary to popular beliefs, teacher-administered education interventions yielded a larger effect than researcher-led ones [86]. This might be because trained classroom teachers, as compared to researchers, were able to provide more immersive interventions and encouraged the transfer of the learned skills to other domains [37]. Therefore, training teachers through PD programs could have a positive downstream effect on their students' learning.

1.6. Empirical Gaps

First, although the SRL framework reflects the iterative, trial-and-error nature of scientific discovery, there is very limited research on the application of SRL and metacognition in science learning during early childhood [13,30]. The relation between metacognition and learning is well established among older children and adult learners [85,87], but more research is needed to investigate how to use science activities to foster young children's metacognition and SRL [30]. The second empirical gap is the lack of research on the features of effective teachers' PD programs designed to support teachers' and children's metacognition and SRL [9]. The quality of teachers' PD programs targeting early science education varies greatly from one-time online workshops to experiential, systematic training over a prolonged period of time [67,88,89]. The development of cognitive skills such as SRL and metacognition require sustained, targeted efforts [90]; however, it is not very clear what kind of PD design facilitates the transformation of teachers' pedagogical knowledge to instructional practices that will eventually benefit children [91,92].

1.7. The Present Study: Aims, Research Questions, and Hypothesis

Informed by the existing literature and empirical gaps, we created a ten-month science education intervention that focuses on SRL and metacognition—Farm to Early Care and Education (Farm to ECE). Farm to ECE adopts a progressive online training plus an in-person coaching model with supplementary curricula that allows teachers to enact their training in real-world scenarios. The goals of this study are twofold: (1) to examine the effect of Farm to ECE on children's SRL and (2) to explore the association between science instructional environment quality and changes in children's SRL. The specific research questions and hypotheses are as follows:

- RQ1: Does the education intervention lead to a significant gain in teacher-level outcomes, as measured by teachers' science teaching efficacy and metacognitive awareness? We hypothesize that the teacher-level outcomes will improve after the education intervention.
- RQ2: Does the education intervention lead to a significant gain in children's SRL scores? We hypothesize that children's SRL will increase after the educationintervention.
- RQ3: To what extent are changes in young children's SRL related to science teaching and environment quality? We hypothesize that better science instructional environment quality is associated with greater improvements in children's SRL.
- RQ4: What insights can be gained from teachers' reporting of children's learning during the education intervention? We hypothesize that teachers' reports will provide authentic information on various aspects of children's learning experiences.

2. Materials and Methods

This mixed-methods study was approved by the Institutional Review Board (IRB) at the lead author's university (IR protocol code 21-233). The data presented in this paper were collected between August 2022 and May 2023.

2.1. Participants

The targeted sample sizes in this study were based on a priori power analysis conducted using the software Optimal Design. The results indicated that 22 teachers and 132 children were needed to detect a statistical significance with an alpha of .05 and a power of .80. Eligible participants were preschool and kindergarten teachers and children (age = 4–6 years, typically developing) within two hours driving distance from the lead author's university from rural regions of north Idaho, U.S. Trained research assistants contacted potential participating teachers via phone calls, emails, and a recruitment event at a regional child development conference in the summer of 2022. Participating teachers then distributed parental consent forms to eligible children in their classrooms. For each teacher, approximately six children were randomly selected for data collection from all the consented children.

A total of 21 teachers consented but one dropped out due to not having eligible children in the classroom ($N_{teacher}$ = 20) (Table 1). On average, the teachers' age was 36.74 years old (*SD* = 10.34, range = 22–57), they were predominately White (75%), 60% had a Bachelor's degree and above, and their teaching experiences ranged from 3 to 29 years (*SD* = 6.69). The child sample consisted of 110 children and had slightly more boys than girls (N_{boy} = 62, N_{girl} = 48), with an average age of 60 months (*SD* = 7.76, range = 44–87).

Table 1. Participants' demographic information.

		N	M/Percent
TEACHER			
Gender:	Male	1	5%
	Female	19	95%
Age (yrs.)		20	36.74
Ethnicity/Race:	Hispanic	3	15%
	Non-Hispanic White	15	75%
	Other	2	10%
Grade:	Preschool	17	95%
	Kindergarten	1	5%
Have a certification		8	40%
Have a CDA		6	30%
Degree:	GED	3	15%
	HS	2	10%

Table 1. *Cont.*

		N	M/Percent
	AA	2	10%
	BA/BS	12	60%
	MA/MS	1	5%
Experience (yrs.)		20	9.35
CHILD			
Gender:	Boys	62	56%
	Girls	48	44%
Age (mo.)		110	60
Ethnicity/Race:	Hispanic	8	7.3%
	Non-Hispanic White	95	86.4%
	Bi- or Multi-racial	7	6.3%

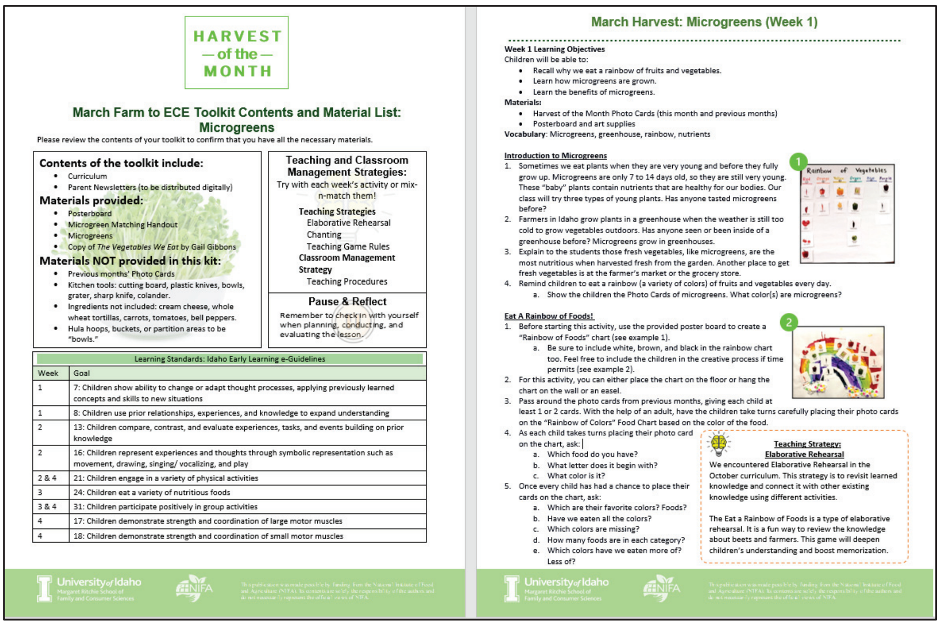
Note. AA = Associate degree, BA/BS = Bachelor's degree, CDA = Child Development Associate Credential, GED = General Education Diploma, HS = High School, MA/MS = Master's degree, mo = month, yrs = years.

2.2. PD Intervention Design and Implementation

This year-long education intervention was in the form of a teachers' PD program and was divided into the spring and fall seasonal segments. In Farm to ECE, teachers were not only learning science background knowledge and developmentally appropriate science teaching practices (e.g., activating prior knowledge, open-ended questions, and sensory learning) via an online learning platform (i.e., Canvas) but also receiving monthly curricula and activity materials (i.e., "Harvest of the Month" toolkit) to facilitate the transformation of pedagogical knowledge into instructional practices and to enrich their science learning environment [67,89].

A typical training module included an introduction video (overview of the curriculum and teaching strategies introduced in that curriculum), a detailed explanation and demonstration of the teaching practices introduced in a given curriculum, and digital resources that complement the curriculum (e.g., song, recipe, dance).

The "Harvest of the Month" toolkit (Figure 1) was distributed to teachers at the beginning of each month. It included seasonal vegetables/grains/fruits (e.g., plums, beets, lentils, microgreens) purchased from local farms, a plant-themed children's book, detailed lesson plans, vocabulary cards, and family engagement newsletters.


HARVEST — of the — MONTH

March Farm to ECE Toolkit Contents and Material List: Microgreens

Please review the contents of your toolkit to confirm that you have all the necessary materials.

Contents of the toolkit include:
- Curriculum
- Parent Newsletters (to be distributed digitally)

Materials provided:
- Posterboard
- Microgreen Matching Handout
- Microgreens
- Copy of *The Vegetables We Eat* by Gail Gibbons

Materials NOT provided in this kit:
- Previous months' Photo Cards
- Kitchen tools: cutting board, plastic knives, bowls, grater, sharp knife, colander.
- Ingredients not included: cream cheese, whole wheat tortillas, carrots, tomatoes, bell peppers.
- Hula hoops, buckets, or partition areas to be "bowls."

Teaching and Classroom Management Strategies:
Try with each week's activity or mix-n-match them!

Teaching Strategies
Elaborative Rehearsal
Chanting
Teaching Game Rules
Classroom Management Strategy
Teaching Procedures

Pause & Reflect
Remember to check in with yourself when planning, conducting, and evaluating the lesson.

Learning Standards: Idaho Early Learning e-Guidelines

Week	Goal
1	7: Children show ability to change or adapt thought processes, applying previously learned concepts and skills to new situations
1	8: Children use prior relationships, experiences, and knowledge to expand understanding
2	13: Children compare, contrast, and evaluate experiences, tasks, and events building on prior knowledge
2	16: Children represent experiences and thoughts through symbolic representation such as movement, drawing, singing/ vocalizing, and play
2 & 4	21: Children engage in a variety of physical activities
3	24: Children eat a variety of nutritious foods
3 & 4	31: Children participate positively in group activities
4	17: Children demonstrate strength and coordination of large motor muscles
4	18: Children demonstrate strength and coordination of small motor muscles

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March Harvest: Microgreens (Week 1)

Week 1 Learning Objectives
Children will be able to:
- Recall why we eat a rainbow of fruits and vegetables.
- Learn how microgreens are grown.
- Learn the benefits of microgreens.

Materials:
- Harvest of the Month Photo Cards (this month and previous months)
- Posterboard and art supplies

Vocabulary: Microgreens, greenhouse, rainbow, nutrients

Introduction to Microgreens
1. Sometimes we eat plants when they are very young and before they fully grow up. Microgreens are only 7 to 14 days old, so they are still very young. These "baby" plants contain nutrients that are healthy for our bodies. Our class will try three types of young plants. Has anyone tasted microgreens before?
2. Farmers in Idaho grow plants in a greenhouse when the weather is still too cold to grow vegetables outdoors. Has anyone seen or been inside of a greenhouse before? Microgreens grow in greenhouses.
3. Explain to the students those fresh vegetables, like microgreens, are the most nutritious when harvested fresh from the garden. Another place to get fresh vegetables is at the farmer's market or the grocery store.
4. Remind children to eat a rainbow (a variety of colors) of fruits and vegetables every day.
   a. Show the children the Photo Cards of microgreens. What color(s) are microgreens?

1 Rainbow of Vegetables

Eat A Rainbow of Foods!
1. Before starting this activity, use the provided poster board to create a "Rainbow of Foods" chart (see example 1).
   a. Be sure to include white, brown, and black in the rainbow chart too. Feel free to include the children in the creative process if time permits (see example 2).
2. For this activity, you can either place the chart on the floor or hang the chart on the wall or an easel.
3. Pass around the photo cards from previous months, giving each child at least 1 or 2 cards. With the help of an adult, have the children take turns carefully placing their photo cards on the "Rainbow of Colors" Food Chart based on the color of the food.
4. As each child takes turns placing their photo card on the chart, ask:
   a. Which food do you have?
   b. What letter does it begin with?
   c. What color is it?
5. Once every child has had a chance to place their cards on the chart, ask:
   a. Which are their favorite colors? Foods?
   b. Have we eaten all the colors?
   c. Which colors are missing?
   d. How many foods are in each category?
   e. Which colors have we eaten more of? Less of?

2

Teaching Strategy: Elaborative Rehearsal
We encountered Elaborative Rehearsal in the October curriculum. This strategy is to revisit learned knowledge and connect it with other existing knowledge using different activities.

The Eat a Rainbow of Foods is a type of elaborative rehearsal. It is a fun way to review the knowledge about beets and farmers. This game will deepen children's understanding and boost memorization.

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Figure 1. Harvest of The Month toolkit example: March microgreen curriculum.

The monthly curriculum included four lesson plans that were supplementary to teachers' primary curriculum—this was to avoid adding too much work into teachers' existing workload. A unique teaching practice (e.g., concept map, scripted reflective prompts) was incorporated into each lesson plan. Teaching practice textboxes were added next to each activity with detailed explanations of the learning science behind the teaching practice. The design of activities was aligned with the Idaho Learning e-Guideline and was developmentally appropriate for 3-to-6-year-old children. The content of the Farm to ECE curriculum was also aligned with the core components of the National Farm to School program.

Each month's activities (see Figure 2 for examples) centered on the basic plant science concepts related to the featured vegetables/grains/fruits while crosscutting several science teaching traditions such as hands-on experiments, storytelling, sensory learning, and child-led inquiry learning traditions [43,45]. For example, week 1 activity typically included an introduction, where teachers presented the real vegetables/grains/fruits to children and encouraged children to explore with all their senses. Week 2 activities usually included more in-depth investigation using science experiments (e.g., sink-or-float experiments with apples and pears) and observation (e.g., beans germination). Week 3 activities were typically shared book reading (e.g., "A Fruit is a Suitcase for Seeds"). The purpose of the week 4 activity was to review what they had learned in the previous weeks using physical movements. For instance, in the "Fruit Tree Yoga" activity, children were asked to recall the lifecycle of a fruit tree and use yoga poses to demonstrate their understanding. The lesson plan of each week's activities details the activity materials, procedures, and scripted open-ended questions that teachers could use to introduce vocabulary words (e.g., beets, rhubarb, hypothesis, investigate), encourage children to make predictions/hypotheses (e.g., "Will the apple sink or float?"), investigate the phenomenon (e.g., "Let us fill the bucket and find out which one sinks and which one floats."), observe and collect evidence (e.g., teachers will record children's hypotheses and the experiment results on a large Post-It easel pad), and discuss the experiment results (e.g., "Take a look at your hypotheses, did you guess it right?", "Why do you think the apple floats but the pear did not?").

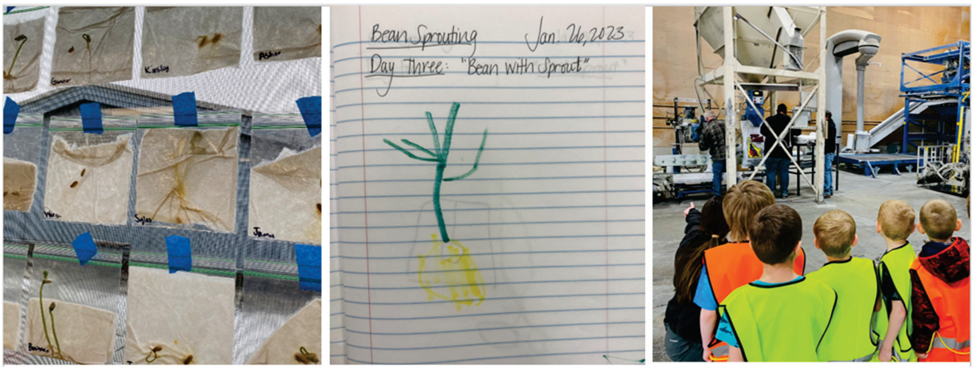

Figure 2. Photographs of the PD program implementation. Note. Left to right: bean germination experiment, bean germination journal, and visiting a local granary.

Metacognitive knowledge (i.e., knowledge about the person, teaching strategies, and teaching tasks [25]), was incorporated into the PD in various forms based on previous research on metacognition intervention. For instance, teachers were required to complete quarterly self-reflection journals and pre- and post-PD assessments [86]. Also, teachers were explicitly taught about metacognition, SRL, science content knowledge related to the curriculum, and science teaching practices (e.g., problematizing modeling, questioning, concept map) using monthly online training modules [91]. Moreover, metacognitive skills (i.e., planning, monitoring, and evaluation) [14] were translated into the PD as journal reflection, workshop, and in-person observation by a trained research assistant [93].

2.3. Procedure

Farm to ECE is a three-year project, and the data presented in this paper were from the year-1 cohort. The year-1 project spanned from September 2022 to May 2023. At the beginning of the PD program in August 2022, teachers participated in a two-and-half hours orientation workshop, led by the first author. The orientation covered topics such as the Farm to ECE curriculum, PD training syllabus, early science learning, metacognition and its application in children's learning, data collection schedule, and Canvas tutorial. Before and after the PD program (i.e., August 2022 and May 2023), teachers completed a series of online and in-person assessments for their science teaching efficacy, metacognitive awareness, science teaching and environment quality, and SRL rating scales. In particular, teachers were required to complete an SRL rating scale for each of the six randomly selected children (with parental consent) in their class during pre- and post-test. During the first week of each month, every teacher received a "Harvest of the Month" toolkit (the toolkit content is described in a previous section) and was required to complete the monthly online training module prior to implementing the curriculum activities by reviewing the online training materials. Teachers' online engagement statistics (e.g., page viewing frequency and duration, etc.) were monitored by the research assistants. The fidelity of the implementation data were collected using an observation tool—Science Teaching and Environment Rating Scale (STERS, [94], α = .94)—at two different time points in November 2022 and April 2023. For each STERS data collection session, trained research assistants observed one Farm to ECE curriculum activity in the classroom and interviewed teachers about their lesson planning and instructional decision-making process after the observation on the same day. The observation field notes and interview transcripts were then independently scored by two trained research assistants using a validated rubric. Upon program completion, each participating teacher received ninety PD credits and a USD 1500 stipend.

2.4. Measurement Instruments

2.4.1. Children's SRL

We measured children's SRL using the Children's Independent Learning Development checklist (CHILD; α = .97; [19]; Appendix A). CHILD is a teacher-reported rating scale that measures children's SRL behaviors. The instrument contains four subscales: cognitive (seven items, e.g., the child adopts previously heard language for own purposes), motivational (five items, e.g., the child plans own tasks, targets, and goals), prosocial (five items, e.g., the child shares and takes turns independently), and emotional subscale (five items, e.g., the child can monitor progress and seeks help appropriately). Each subscale uses a four-point Likert scale ranging from Never (1) to Always (4). Given the time commitment of the entire teacher- and child-assessment battery, we did not include the Emotional and Prosocial subscales to avoid overwhelming teachers.

2.4.2. Science Teaching and Environment Quality

Science learning environment quality was measured by the Science Teaching and Environment Rating Scale (STERS; [94], α = .94; Appendix B). STERS assesses the quality of science teaching and environment in early childhood classrooms by drawing on classroom observation and teacher interview data. Trained research assistants observed the classroom science learning environment and a science learning activity from the Farm to ECE curriculum twice a year in the spring and fall semesters. The research assistants then interviewed the teachers about their instructional decision making using a structured interview protocol (Eight questions, e.g., What have you learned about children's understanding of this topic up to this point? Do you use this information for planning, if so, how?). In total, there were 40 observation field notes and 40 interview recordings (average length: eight minutes).

Observation field notes and interview transcripts were scored on a 4-point validated rubric (1 = deficient to 4 = exemplary) across eight indicators: (1) creates a physical environment for inquiry and learning (e.g., provides access to science learning materials), (2) facilitates direct experiences to promote conceptual learning (e.g., engages learners and assists their learning), (3) promotes the use of scientific inquiry (e.g., intentionally facilitates science process skills), (4) creates a collaborative climate that promotes exploration and understanding (e.g., fosters a science learning environment where children's ideas are valued), (5) provides opportunities for extended conversations (e.g., promotes multi-turn discussion), (6) builds children's vocabulary (e.g., introduces new words), (7) plans in-depth investigations (e.g., provides sufficient time for exploration), and (8) assesses children's learning (e.g., uses on-going assessments). Two trained research assistants scored the observation and interview data independently (κ = .91). Each teacher's STERS score was derived from two sets of observations and interviews collected in the fall and spring semesters. RAs resolved the scoring differences by discussing the scoring results with the lead author.

2.4.3. Teachers' Science Teaching Efficacy

Teachers' science teaching efficacy was measured by the Science Teaching Efficacy and Beliefs (STEB; [95], α_{STEB} = .90; Appendix C) and Science Teaching Outcome Expectancy (STOE; α_{STOE} = .93) subscales in the Elementary Teacher Efficacy and Attitudes toward STEM Surveys (T-STEM; [95]). STEB and STOE are five-point Likert scales that include 40 items in total. An example of a STEB scale item is "When a student has difficulty understanding science concept, I am confident that I know how to help the student understand it better". An example of a STOE scale item is "Students' learning in science is directly related to their teacher's effectiveness in science teaching".

2.4.4. Teachers' Metacognitive Awareness

The Metacognitive Awareness Inventory for Teachers (MAIT; [96]; Appendix D) was used to measure teachers' metacognitive awareness. The MAIT involves 24 items on a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The three subscales that measure metacognitive knowledge are declarative knowledge (α = .63, e.g., I am aware of the strengths and weaknesses in my teaching), procedural knowledge (α = .61, e.g., I try to use teaching techniques that worked in the past), and conditional knowledge (α = .63, e.g., I use different teaching techniques depending on the situation). The three subscales that measure metacognitive regulation are planning (α = .73, e.g., I organize my time to best accomplish my teaching goals), monitoring (α = .71, e.g., I ask myself questions about how well I am doing while I am teaching), and evaluating (α = .76, e.g., I ask myself if I could have used different techniques after each teaching experience).

2.4.5. Qualitative Data Collection

For the qualitative data collection, teachers completed four online quarterly reflection journal entries on Canvas. Each entry included five writing prompts that required teachers to reflect on and provide examples of children's activity engagement, things that went well, challenges they encountered, and teaching strategies or science background knowledge that they wished they knew more about (e.g., How was children's engagement? What did not go as planned and how did you resolve it?).

2.5. Data Analysis

We first conducted descriptive analysis to examine the normality of the data and test the assumptions for the subsequent analysis. A series of repeated measures analyses of variance (ANOVA) [97] were used to test the first two hypotheses. Teachers' and children's outcome variables were entered as the dependent variables in each model, respectively. To test the third hypothesis, we used linear mixed models to account for the data's nested structure (i.e., children were clustered in classrooms/teachers). Individual children's scores were centered at the group level to improve the results' interpretability [98]. Fully unconditional models were run before adding predictors [99]. Intraclass correlation (ICC) indicated that the common variance shared at the cluster level (ICC_{cog} = .12, ICC_{mot} = .24) warranted the use of linear mixed modeling [99]. Child-level variables were then entered at level-1, and teacher-level variables were entered at level-2. Software R (Version 4.3.1) and R package lme4 [100] were used.

Qualitative data were analyzed using a thematic analysis method to identify recurring patterns in the data [101]. A trained graduate research assistant combed through teachers' reflection journal entries and assigned open codes to emerging phenomena. The research assistant then conducted axial coding by further grouping open codes into larger categories (i.e., axial codes) and identifying the relations between the axial codes. For the final step, the leader author and three research assistants held a meeting to discuss axial coding results and emerging themes. Detailed memos, peer debriefing, and the involvement of multiple coders enhanced the credibility of the qualitative data analysis [102].

3. Results

In this section, we describe the data analysis results organized by using the research questions. We first present whether and to what extent the PD program impacted children and teachers' outcomes, and then discuss the relation between science teaching and environment quality improvement to children's SRL scores. Finally, we review the qualitative evidence of teacher-reported children's learning and challenges related to the PD program implementation.

3.1. PD's Impact on Teachers' Metacognitive Awareness and Science Teaching Efficacy

A series of repeated measures ANOVA were used to answer RQ1: Does the education intervention lead to a significant gain in teacher-level outcomes, as measured by science instructional environment quality, teachers' science teaching efficacy, and metacognitive awareness? We did not control any covariates because this study adopted a within-subject repeated measure experimental design; therefore, potential covariates such as teachers' degrees and years of teaching experience were already controlled. Although our sample was slightly smaller than the target sample size, the data analysis results showed some positive effects of the PD program on teachers' outcomes (Figure 3), which partially confirmed our first hypothesis. Specifically, after the PD program, there was an increase in teachers' science teaching efficacy beliefs ($F_{efficacy}(1, 19) = 11.12$, $p = .003$, $\eta^2 = .37$, average score increase post-PD: 4.15) and science teaching outcome expectancy ($F_{expectancy}(1, 19) = 4.33$, $p = .05$, $\eta^2 = .19$; average score increase post-PD: 2.55). Also, teachers' metacognitive knowledge awareness showed meaningful improvement after the PD program ($F_{awawre}(1, 19) = 6.90$, $p = .02$, $\eta^2 = .27$, average score increase post-PD: 2.65). Contrary to what was expected, teachers' metacognitive regulation skills were not statistically different before and after the PD ($F_{reg}(1, 19) = 1.76$, $p = .20$).

3.2. Children's SRL

To answer RQ2—Does the education intervention lead to a significant gain in children's SRL scores?—we conducted linear mixed modeling with child outcomes at level-1. There was no predictor added at level-2, which only accounted for the unobserved variance explained by the class/teacher differences. The cognitive and motivational subscales showed satisfactory reliability in our sample ($\alpha_{cog} = .96$, $\alpha_{mot} = .90$). The results indicate that there was an increase in teacher-reported children's cognitive skills ($F(1, 109) = 20.08$, $p < .001$, $\eta^2 = .16$), with an average of 1.68 points increase after the PD. There was also a significant improvement in children's learning motivation ($F(1, 109) = 13.50$, $p < .001$, $\eta^2 = .11$), with an average of .14 points increase post-PD (Figure 3). The data analysis results confirm our second hypothesis.

3.3. The Association between Science Teaching and Environment Quality and Children's SRL

To answer RQ3—To what extent are changes in young children's SRL related to science teaching and environment quality?—linear mixed modeling was used with children's cognitive and motivation gain scores (i.e., post-test scores minus pre-test scores) at level-1 and teachers' science teaching and environment quality at level-2. Note that the science teaching and environment quality scores were not used as pre-test and post-test scores because data were collected in November 2022 and April 2023 for fidelity monitoring and PD coaching purposes. The science teaching and environment quality scores were derived from data collected at both time points in order to better represent the quality of the science instructional environment. The results showed that gain scores in the cognitive ($t(14)$ = 2.33, β = .24, p = .02) and motivational ($t(14)$ = 2.16, β = .15, p = .03) aspects of SRL were significantly associated with the quality of science instructional practices and learning environment. In other words, children tended to have better SRL skills when their teachers had better science teaching practices and when their classroom environment was conducive to science learning.

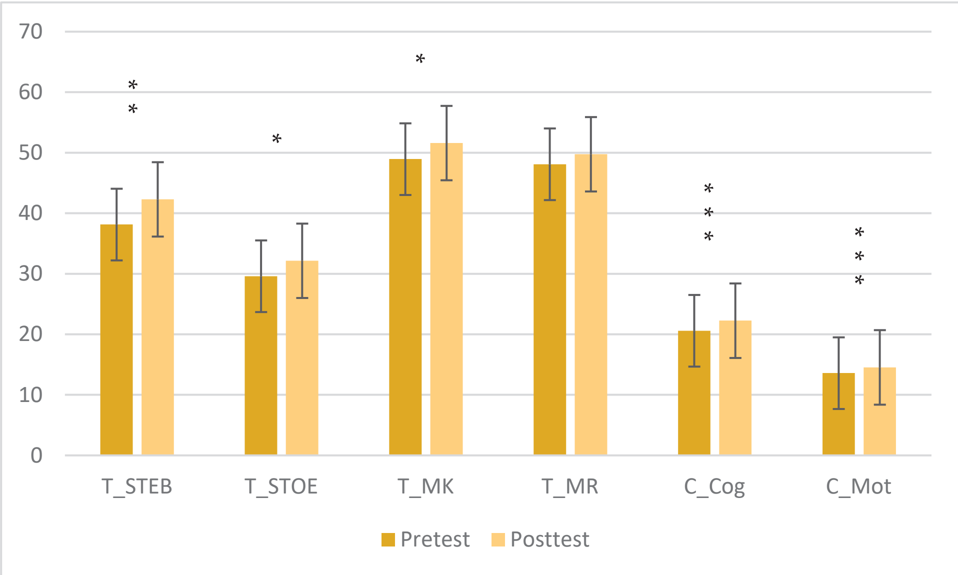

Figure 3. Teacher's and children's pre-test and post-test results. Note. * p < .05, ** p < .01, *** p < .001, C = child, Cog = cognition, MK = metacognitive knowledge, Mot = motivation, MR = metacognitive regulation, STEB = science teaching efficacy beliefs, STOE = science teaching outcome expectancy.

3.4. Qualitative Evidence

To answer RQ4—What insights can be gained from teachers' reporting of children's learning during the education intervention?—we used a thematic analysis method to analyze teachers' structured reflection journals. The results are discussed by themes below.

3.4.1. Children's Learning Interests and Engagement

Teachers' written reports revealed evidence of children's strong interests in the curriculum materials, particularly those hands-on activities (e.g., bean germination experiment, learning games, and fruits/vegetables/grains exploration). For example, a teacher wrote: "*Overall, their engagement was exceptional. Each child had an excitement in the fruits and vegetables being discussed and we were all able to connect over different home/life experiences with the material and the lesson*". Another teacher reflected: "*My preschoolers loved learning about fruits and vegetables during September and October*. . .. *having the actual fruits and vegetables to see, smell, feel, and taste was very fun for them!*". However, several teachers mentioned that younger preschool children tended to lose interest quicker than older children.

3.4.2. Science Activities Support Learning in Other Subject and Developmental Domains

The Farm to ECE curriculum primarily focused on the teaching of basic plant science concepts; however, qualitative data analysis showed evidence that this curriculum also supported children's learning in other subject domains (e.g., literacy, mathematics) and developmental domains (e.g., inquiry skills and self-regulation skills). For example, a teacher reflected on teaching children thinking vocabulary (i.e., predict, observe, compare):

> *In week one of September, the "thinking vocabulary" was very beneficial for myself and my students. We explicitly went over each of the vocabulary terms, and then we dove right into the lesson. During the lesson, I repetitively used the words "predict, observe, and compare", and I could tell that my students felt like little scientists, which is exactly what they were!*

A teacher reflected on children's inquiry and mathematics skills during the bean germination experiment: "*My class enjoyed playing, sorting, and weighing beans. We germinated them as instructed in plastic bags first then transferred them to bigger containers. We started measuring and taking notice of how fast or slow each plant grew*". Another teacher wrote about how children document evidence in the bean germination experiment: "*The child loved to watch the different beans grow and then be able to draw the progress on their journal. They would always ask to see how much the beans have sprouted!*". The same teacher also reflected on how children were motivated to initiate new investigations: "*The best highlight is the children asking if we could plant our own seeds from our apples and what other vegetables we could grow in our garden*". A different teacher described children's self-regulation skills during a small-group activity: "*The children patiently waited their turn and followed directions well when we planted their bean plant*".

4. Discussion

The goal of this ongoing three-year study is to examine the effect of a metacognitive-driven, experiential early science instructional intervention on children's SRL and to explore the relation between science instructional environment quality and the improvement in children's SRL. Quantitative and qualitative analyses of the year-1 data showed that the PD program yielded positive impacts on teachers' and children's outcomes, such as science teaching efficacy, metacognitive awareness of teaching, and children's SRL. We also found a small but significant correlation between science instructional environment quality and the children's improvement in SRL. In this section, we discuss our research findings, limitations, and future directions.

4.1. Early Science Education and Children's SRL

As expected, we found a statistically significant increase in both the cognitive and motivational aspects of young children's SRL after the PD program (controlling for children's age), and this improvement was positively associated with the quality of science teaching and environment quality. Our quantitative finding was supported by teachers' qualitative reports of children's learning interests and inquiry skills (e.g., observe, document, initiate new investigation). The connection between children's SRL skills gains and early science teaching and environment quality could imply that early science learning promoted young children's SRL [55]. The positive association between science teaching environment quality and children's SRL in our study, although interesting, did not warrant causation. We encourage future researchers to employ a randomized control trial to investigate the potential causal relation between early childhood science education and SRL, as well as to unpack why this relation exists.

Despite the benefit of early science learning, science is an overlooked subject area in early childhood classrooms. For instance, on average, preschool teachers dedicated only 9% of classroom learning time to science, which is significantly lower than literacy (30%) and math (19%) [74]. The current state of early science learning could be due to insufficient teacher training about science pedagogical content knowledge [79] and the lack of resources [80], in particular the lack of developmentally appropriate science curriculum that also touches on other subject and developmental domains (e.g., literacy, math, social-emotional development).

The Farm to ECE curriculum filled the gaps described above by integrating literacy and mathematics contents in the science curriculum while promoting children's self-regulation skills. For example, in the "Peaches & Plums" unit, children not only learned science concepts about fruits (e.g., lifecycles and growing conditions) but also new vocabulary words (e.g., pit, fuzz, and ripe). In the "Radishes" unit, children gained mathematic competency by measuring and weighing radishes and exercising their self-regulation skills in a small group activity where children used scientific tools (e.g., magnifying glasses and scales) to explore radishes. Moreover, this curriculum uses locally sourced fruits/vegetables/grains as children's place-based hands-on learning materials, which were connected with rural children and teachers' lived experiences. Our finding is supported by the results from a recent meta-analysis study: teacher-administered interventions targeting children's SRL yielded a bigger effect than those administered by interventionists, possibly due to teachers' extensive knowledge about their children and the ability to conduct immersive training that encouraged knowledge transfer [86]. Given the positive impact of early science learning on children's SRL, as indicated by our data analysis results, future researchers and early childhood policymakers should create and fund evidence-based, integrative early science curricula; such curricula should also be supplemented by teacher training to maximize its benefit [71].

4.2. The PD's Impact on Teachers' Outcomes

As for the teacher-level outcome, our data analysis results showed that the metacognition-driven early science learning PD meaningfully improved early childhood teachers' science teaching efficacy. It is worth noting that we observed an increase not only in teachers' science teaching efficacy beliefs but also outcome expectancy post-PD. Previous research has shown that early childhood teachers' training did not necessarily lead to positive changes in the outcome expectancy aspect of science teaching efficacy [103]. In other words, teacher training that focuses on content knowledge and pedagogy may increase teacher-perceived science teaching ability but not the perceived impact of their teaching. A plausible explanation is that science teaching outcome expectancy involves many factors beyond teachers' control, such as children's learning interests and contextual factors (e.g., resources and behavior management) [104]. We credit the increase in teachers' science teaching outcome expectancy in our program to the immersive, hands-on curriculum. The Farm to ECE PD program uses a year-long supplementary curriculum to accompany the monthly online training, and this combination possibly aided the translation of pedagogical content knowledge to classroom teaching practices, therefore leading to increased science teaching outcome expectancy. Future work is needed to understand the multifaceted factors that contribute to teachers' knowledge transformation to classroom practices (e.g., PD training regimen, curriculum, teacher attitudes, and class sizes).

Our results also showed an increase in teachers' metacognitive knowledge about their teaching practices; however, the PD did not have an effect on their regulation skills regarding teaching (i.e., planning, monitoring, and evaluation). The Farm to ECE program adopted several ways to enhance teachers' metacognitive awareness for teaching. For instance, we added "Teaching/Classroom Management Strategies Boxes" to each curriculum activity to explain the science behind these evidence-based instructional practices and how to use them with young children. These practices were explained in greater detail in teachers' monthly training videos on the online PD platform. The curriculum activities allowed teachers to practice using the teaching/classroom management strategies taught in the PD. In addition, teachers were asked to write quarterly reflections about their classroom implementations. The Farm to ECE PD design echoed previous successful PDs that aimed to enhance teachers' and students' metacognition [105–107].

As to the null finding on teachers' metacognitive regulation skills, a possible explanation is the need for more teachers' autonomy in our program. The current Farm to ECE PD program was prescribed to teachers—the lesson plan, learning goals, activities, and materials were predetermined in the monthly curriculum. As a result, there was not much room in the curriculum for teachers to proactively exercise their planning, monitoring, and evaluation skills. Future PD programs could consider using a semi-structured PD framework to allow teachers to co-design the PD with researchers in order to promote teachers' autonomy and metacognitive regulation skills [83]. Another possible explanation for the null finding is related to measurement. The MAIT explores a teacher's self-reported measurement and is not designed for any specific grade level or content area [96]. Therefore, MAIT items may not accurately reflect early childhood teachers' metacognition related to science teaching, and teachers' responses may be subject to social desirability [108]. Content-specific direct measurements of teachers' metacognition are needed in order to provide reliable data on teachers' awareness of their content and pedagogical knowledge. Future researchers could consider developing such measurements using a response-contingent signal detection approach (i.e., type-2 signal detection). Başokçu and Güzel [109] successfully created this type of instrument to measure elementary teachers' mathematics teaching metacognition. Such a measurement approach could be expanded to other grades and content areas.

4.3. Limitations and Future Directions

In this section, we discuss several limitations and how future research may overcome these limitations and advance studies on metacognition and early science teaching and learning. First, the participants in our study were predominately White and from rural areas of Northern Idaho, and the sample size was slightly underpowered. Therefore, our sample was homogenous and is not representative of the larger population in the U.S. The results from this study should be interpreted within their context. Future research should consider recruiting a larger sample from a more demographically diverse population (e.g., urban, inner city). Secondly, a number of measurements used in this study were self-reported and teacher-reported instruments (e.g., CHILD, STEB, STOE, and MAIT), which may have introduced social desirability bias and rater's bias [108]. Future researchers who are interested in a similar topic should consider using or creating direct measurements of children's SRL [110] and teacher's metacognitive awareness in teaching [109]. Third, the outcome of the PD was measured immediately after the program, and we do not have data to demonstrate the long-term impact of this program. Future PD studies should examine delayed effects as well as acute effects in order to investigate the possible lasting impact and transfer effects of a PD program. Fourth, the qualitative data collected in this study (i.e., reflection journals) lacked richness. Additional qualitative data, such as teachers' interviews, will enable a more in-depth interpretation of results from this mixed-methods study. Fifth, child-level outcomes were limited to SRL, and measurements that assess children's science learning conceptual changes were absent. Future studies should measure not only changes in children's learning skills but also knowledge retainment as well. The sixth limitation is related to the PD design. Although we created curriculum activities that promote sensory learning and child-directed exploration, there is a lack of immersive problem-based learning. To improve the current design, we plan to create more open-ended inquiry learning tasks (e.g., germinating and growing beans, creating compost) to better instill the idea that science is a dynamic discovery process. Last but not least, we only used the cognitive and motivational subscales of CHILD. We decided to not include emotional and prosocial subscales to lessen teachers' workload, given their existing tasks. Future work is needed to examine the relation between science learning and all aspects of SRL.

5. Conclusions

Self-regulated learners are competent at setting learning goals, selecting effective learning strategies, monitoring and evaluating task performances, and persevering despite challenges [4]. We argue that early science learning might be an overlooked prime context to supporting children's self-regulated learning (SRL) because science activities capitalize on children's innate curiosity and allow children to exercise the motivational (meta)cognitive and self-regulation aspects of SRL. Our research findings show the potential of supporting children's SRL by training early childhood teachers to conduct science activities using a combination of professional development and experiential curriculum. Particularly, children's improvement in SRL could in part be attributed to teachers' skillfulness in leading science activities (e.g., promoting children's inquiry learning and sense-making) and the quality of the science learning environment (e.g., a classroom containing developmentally appropriate science materials that afford exploration and learning). Overall, the Farm to ECE program supported children's SRL, holistic understanding of basic plant science concepts and science process skills, and teachers' science teaching efficacy and metacognitive awareness as well.

Our study also has implications regarding the unique challenges and strengths related to conducting education research with rural populations in the U.S. Idaho ranks 44th of the 50 states in population density, averaging 22.3 per square mile [111] As a result, we were only able to enroll 20 childcare centers. The majority of the childcare centers in this study were located in dispersed rural areas within a 2 h radius from the lead author's university, which inevitably increased the cost of delivering PD materials and instructional coaching. However, the teachers seemed to be very enthusiastic about the PD content, and only one teacher dropped out due to not having enough eligible children in her classroom. We attribute our high retention rate to the fact that early childhood teachers, especially those in remote rural areas, receive very limited financial and training support and are eager for content-rich PD and curriculum that are related to their lived experiences in rural areas (i.e., agriculture, gardening). Early childhood teachers in rural areas are one of the least studied populations, and future researchers should be mindful of the challenges and strengths associated with conducting research with this population. In particular, place-based PD (e.g., PD centered on the farm culture) seemed to gain traction among rural teachers. Future researchers and policymakers should continue to create and support place-based, experiential PD and curriculum for early childhood teachers and children in rural communities.

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Appendix A. Children's Independent Learning Development Checklist

Based on your recent observation of the child in the past two months, this child:

Self-Regulated Learning Skills	Always	Usually	Sometimes	Never
Emotional				
1. Can speak about own and others' behavior and Consequences.				
2. Tackles new tasks confidently.				
3. Can control attention and resist distraction.				
4. Monitors progress and seeks help appropriately.				
5. Persists in the face of difficulties.				

Self-Regulated Learning Skills	Always	Usually	Sometimes	Never
Prosocial				
1. Negotiates when and how to carry out tasks.				
2. Can resolve social problems with peers.				
3. Shares and takes turns independently.				
4. Engages in independent cooperative activities with peers.				
5. Is aware of feelings of others and helps and comforts.				
Cognitive				
1. Is aware of own strengths and weaknesses.				
2. Can speak about how they have done something or what they have learned.				
3. Can speak about future planned activities.				
4. Can make reasoned choices and decisions.				
5. Asks questions and suggests answers.				
6. Uses previously taught strategies.				
7. Adopts previously heard language for own purposes.				
Motivational				
1. Finds own resources without adult help				
2. Develops own ways of carrying out tasks				
3. Initiates activities				
4. Plans own tasks, targets, and goals				
5. Enjoys solving problems				

Appendix B. Science Teaching and Environment Quality

Note. Only the interview protocol is shown in Appendix B due to the size of the full instrument and copyright issues. Interested users can contact the Educational Development Center https://edc.org/ (accessed on 6 May 2024) for the full instrument and training.

Introduction Script

Today is____________________ (month/day/year), I'm with ________ (teachers' name), ID number______. I just observed the ______activity featuring ________ (fruit/veggie/grain). I have 4 questions about the activity you did today. There are no right or wrong answers, we are simply interested in your opinion.

Interview Questions

1. Reflect on the activity you did today, how did you prepare for this topic? How did you introduce the children to this topic?
2. What have you learned about children's understanding of this topic up to this point?
    a. How have you learned this?
    b. Do you document learning in any way?
    c. How do you keep and use your information about children's science learning? "Science" here refers to the food and agriculture knowledge in the Farm to ECE curriculum.
    d. Do you use this information in planning? If so, how?
3. What additional materials and activities do you plan to provide related to this topic and why?
4. What are the most important strategies you use to support children's science learning? "Science" here refers to the food and agriculture knowledge in the Farm to ECE curriculum.

Appendix C. Science Teaching Efficacy Beliefs and Outcome Expectancy

There are no right or wrong answers in this list of statements. It is simply a matter of what is true for you. Read every statement carefully and choose the one that best describes you.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
Science Teaching Efficacy Beliefs					
I am continually improving my science teaching practice.					
I know the steps necessary to teach science effectively.					
I am confident that I can explain to students why science experiments work.					
I am confident that I can teach science effectively.					
I wonder if I have the necessary skills to teach science.					
I understand science concepts well enough to be effective in teaching science.					
Given a choice, I would invite a colleague to evaluate my science teaching.					
I am confident that I can answer students' science questions.					
When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.					
When teaching science, I am confident enough to welcome student questions.					
I know what to do to increase student interest in science.					
Science Teaching Outcome Expectancy					
When a student does better than usual in science, it is often because the teacher exerted a little extra effort.					
The inadequacy of a student's science background can be overcome by good teaching.					
When a student's learning in science is greater than expected, it is most often due to their teacher having found a more effective teaching approach.					
The teacher is generally responsible for students' learning in science.					
If students' learning in science is less than expected, it is most likely due to ineffective science teaching.					
Students' learning in science is directly related to their teacher's effectiveness in science teaching.					
When a low achieving child progresses more than expected in science, it is usually due to the extra attention given by the teacher.					
If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.					
Minimal student learning in science can generally be attributed to their teachers.					

Appendix D. Metacognitive Awareness Inventory for Teachers

There are no right or wrong answers in this list of statements. It is simply a matter of what is true for you. Read every statement carefully and choose the one that best describes you.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
▪ I am aware of the strengths and weaknesses in my teaching.					
▪ I try to use teaching techniques that worked in the past.					

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
▪ I use my strengths to compensate for my weaknesses in my teaching.					
▪ I pace myself while I am teaching in order to have enough time.					
▪ I ask myself periodically if I meet my teaching goals while I am teaching.					
▪ I ask myself how well I have accomplished my teaching goals once I am finished.					
▪ I know what skills are most important in order to be a good teacher.					
▪ I have a specific reason for choosing each teaching technique I use in class.					
▪ I can motivate myself to teach when I really need to teach.					
▪ I set my specific teaching goals before I start teaching.					
▪ I find myself assessing how useful my teaching techniques are while I am teaching.					
▪ I ask myself if I could have used different techniques after each teaching experience.					
▪ I have control over how well I teach.					
▪ I am aware of what teaching techniques I use while I am teaching					
▪ I use different teaching techniques depending on the situation.					
▪ I ask myself questions about the teaching materials I am going to use.					
▪ I check regularly to what extent my students comprehend the topic while I am teaching.					
▪ After teaching a point, I ask myself if I'd teach it more effectively next time.					
▪ I know what I am expected to teach.					
▪ I use helpful teaching techniques automatically.					
▪ I know when each teaching technique I use will be most effective.					
▪ I organize my time to best accomplish my teaching goals.					
▪ I ask myself questions about how well I am doing while I am teaching.					
▪ I ask myself if I have considered all possible techniques after teaching a point.					

References

1. Taranto, D.; Buchanan, M.T. Sustaining lifelong learning: A self-regulated learning (SRL) approach. *Discourse Commun. Sustain. Educ.* **2020**, *11*, 5–15. [CrossRef]
2. Panadero, E. A review of self-regulated learning: Six models and four directions for research. *Front. Psychol.* **2017**, *8*, 422. [CrossRef]
3. Zimmerman, B.J. Self-regulated learning and academic achievement: An overview. *Educ. Psychol.* **1990**, *25*, 3–17. [CrossRef]

4. Schunk, D.H.; Greene, J.A. *Handbook of Self-Regulation of Learning and Performance*; Routledge: London, UK, 2017. [CrossRef]
5. Dent, A.L.; Koenka, A.C. The relation between self-regulated learning and academic achievement across childhood and adolescence: A meta-analysis. *Educ. Psychol. Rev.* **2016**, *28*, 425–474. [CrossRef]
6. Chu, L.; Li, P.H.; Yu, M.N. The longitudinal effect of children's self-regulated learning on reading habits and well-being. *Int. J. Educ. Res.* **2020**, *104*, 101673. [CrossRef]
7. Mahatmya, D.; Lohman, B.J.; Matjasko, J.L.; Farb, A.F. Engagement across developmental periods. In *Handbook of Research on Student Engagement*, 1st ed.; Christenson, S.L., Reschly, A.L., Wylie, C., Eds.; Springer: Berlin, Germany, 2012; pp. 45–63. [CrossRef]
8. McLaughlin, K.A.; Sheridan, M.A.; Humphreys, K.L.; Belsky, J.; Ellis, B.J. The value of dimensional models of early experience: Thinking clearly about concepts and categories. *Perspect. Psychol. Sci.* **2021**, *16*, 1463–1472. [CrossRef] [PubMed]
9. Whitebread, D.; Neale, D. Metacognition in early child development. *Transl. Issues Psychol. Sci.* **2020**, *6*, 8. [CrossRef]
10. Şen, Ş.; Yılmaz, A.; Geban, Ö. The effects of process oriented guided inquiry learning environment on students' self-regulated learning skills. *Probl. Educ. 21st Century* **2015**, *66*, 54–66. [CrossRef]
11. Ucan, S.; Webb, M. Social regulation of learning during collaborative inquiry learning in science: How does it emerge and what are its functions? *Int. J. Sci. Educ.* **2015**, *37*, 2503–2532. [CrossRef]
12. Winne, P.H. Modeling self-regulated learning as learners doing learning science: How trace data and learning analytics help develop skills for self-regulated learning. *Metacogn. Learn.* **2022**, *17*, 773–791. [CrossRef]
13. Avargil, S.; Lavi, R.; Dori, Y.J. Students' metacognition and metacognitive strategies in science education. *Cogn. Metacogn. Cult. STEM Educ.* **2018**, *24*, 33–64. [CrossRef] [PubMed]
14. Zohar, A.; Barzilai, S. A review of research on metacognition in science education: Current and future directions. *Stud. Sci. Educ.* **2013**, *49*, 121–169. [CrossRef]
15. Zimmerman, A.; Moylan, B. *Handbook of Metacognition in Education*; Routledge: London, UK, 2009.
16. Bjorklund, D.F. *Children's Thinking: Cognitive Development and Individual Differences*; Sage: Thousand Oaks, CA, USA, 2022.
17. Landis, T.; Hart, C.; Graziano, P. Targeting self-regulation and academic functioning among preschoolers with behavior problems: Are there incremental benefits to including cognitive training as part of a classroom curriculum? *Child Neuropsychol.* **2019**, *25*, 668–704. [CrossRef] [PubMed]
18. Bronson, M.B.; Bronson, M. *Self-Regulation in Early Childhood: Nature and Nurture*; Guilford Press: New York, NY, USA, 2001.
19. Whitebread, D.; Coltman, P.; Pasternak, D.P.; Sangster, C.; Grau, V.; Bingham, S.; Almeqdad, Q.; Demetriou, D. The development of two observational tools for assessing metacognition and self-regulated learning in young children. *Metacogn. Learn.* **2009**, *4*, 63–85. [CrossRef]
20. Dörr, L.; Perels, F. Improving metacognitive abilities as an important prerequisite for self-regulated learning in preschool children. *Int. Electron. J. Elem. Educ.* **2019**, *11*, 449–459. [CrossRef]
21. Azevedo, R. Reflections on the field of metacognition: Issues, challenges, and opportunities. *Metacogn. Learn.* **2020**, *15*, 91–98. [CrossRef]
22. Flavell, J.H. Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *Am. Psychol.* **1979**, *34*, 906–911. [CrossRef]
23. Marulis, L.M.; Nelson, L.J. Metacognitive processes and associations to executive function and motivation during a problem-solving task in 3–5 year olds. *Metacogn. Learn.* **2021**, *16*, 207–231. [CrossRef]
24. Rouault, M.; McWilliams, A.; Allen, M.G.; Fleming, S.M. Human metacognition across domains: Insights from individual differences and neuroimaging. *Personal. Neurosci.* **2018**, *1*, e17. [CrossRef] [PubMed]
25. Schraw, G.; Moshman, D. Metacognitive theories. *Educ. Psychol. Rev.* **1995**, *7*, 351–371. [CrossRef]
26. Escolano-Pérez, E.; Herrero-Nivela, M.L.; Anguera, M.T. Preschool metacognitive skill assessment in order to promote an educational sensitive response from mixed-methods approach: Complementarity of data analysis. *Front. Psychol.* **2019**, *10*, 1298–1309. [CrossRef]
27. Gonzales, C.R.; Merculief, A.; McClelland, M.M.; Ghetti, S. The development of uncertainty monitoring during kindergarten: Change and longitudinal relations with executive function and vocabulary in children from low-income backgrounds. *Child Dev.* **2022**, *93*, 524–539. [CrossRef] [PubMed]
28. Jean, P.; Inhelder, B. *The Psychology of the Child*; Basic Books: New York, NY, USA, 2008.
29. Wimmer, H.; Perner, J. Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition* **1983**, *13*, 103–128. [CrossRef]
30. Chen, S.; McDunn, B. Metacognition: History, measurements, and the role in early childhood development and education. *Learn. Motiv.* **2022**, *78*, 101786. [CrossRef]
31. Marulis, L.M.; Palincsar, A.S.; Berhenke, A.L.; Whitebread, D. Assessing metacognitive knowledge in 3–5 year olds: The development of a metacognitive knowledge interview (McKI). *Metacogn. Learn.* **2016**, *11*, 339–368. [CrossRef]
32. Kattner, F.; Bryce, D. Attentional control and metacognitive monitoring of the effects of different types of task-irrelevant sound on serial recall. *J. Exp. Psychol. Hum. Percept. Perform.* **2022**, *48*, 139–158. [CrossRef]
33. Roebers, C.M.; van Loon, M.H.; Buehler, F.J.; Bayard, N.S.; Steiner, M.; Aeschlimann, E.A. Exploring psychometric properties of children' metacognitive monitoring. *Acta Psychol.* **2021**, *220*, 103399. [CrossRef] [PubMed]

34. Fleming, S.; Dolan, R. The neural basis of metacognitive ability. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2012**, *367*, 1338–1349. [CrossRef]
35. Metcalfe, J.; Schwartz, B.L. The ghost in the machine: Self-reflective consciousness and the neuroscience of metacognition. In *Oxford Handbook of Metamemory*; John, D., Sara, T., Eds.; Oxford University Press: Oxford, UK, 2016; pp. 407–424. [CrossRef]
36. Eberhart, J.; Bryce, D.; Baker, S. *Staying Self-Regulated in the Classroom: The Role of Children's Executive Functions and Situational Factors*; OSF: Peoria, IL, USA, 2023. [CrossRef]
37. Perry, N.E.; VandeKamp, K.O.; Mercer, L.K.; Nordby, C.J. Investigating teacher-student interactions that foster self-regulated learning. In *Using Qualitative Methods to Enrich Understandings of Self-Regulated Learning*; Perry, N., Ed.; Routledge: London, UK, 2023; pp. 5–15. [CrossRef]
38. Dignath, C.; Veenman, M.V. The role of direct strategy instruction and indirect activation of self-regulated learning—Evidence from classroom observation studies. *Educ. Psychol. Rev.* **2021**, *33*, 489–533. [CrossRef]
39. Ergen, B.; Kanadli, S. The effect of self-regulated learning strategies on academic achievement: A meta-analysis study. *Eurasian J. Educ. Res.* **2017**, 17. [CrossRef]
40. Schuster, C.; Stebner, F.; Geukes, S.; Jansen, M.; Leutner, D.; Wirth, J. The effects of direct and indirect training in metacognitive learning strategies on near and far transfer in self-regulated learning. *Learn. Instr.* **2023**, *83*, 101708. [CrossRef]
41. Sukowati, S.; Sartono, E.; Pradewi, G. The effect of self-regulated learning strategies on the primary school students' independent learning skill. *Psychol. Eval. Technol. Educ. Res.* **2020**, *2*. [CrossRef]
42. Theobald, M. Self-regulated learning training programs enhance university students' academic performance, self-regulated learning strategies, and motivation: A meta-analysis. *Contemp. Educ. Psychol.* **2021**, *66*, 101976. [CrossRef]
43. Xu, Z.; Zhao, Y.; Zhang, B.; Liew, J.; Kogut, A. A meta-analysis of the efficacy of self-regulated learning interventions on academic achievement in online and blended environments in K-12 and higher education. *Behav. Inf. Technol.* **2023**, *42*, 2911–2931. [CrossRef]
44. Garcia, R.; Falkner, K.; Vivian, R. Systematic literature review: Self-regulated learning strategies using e-learning tools for Computer Science. *Comput. Educ.* **2018**, *123*, 150–163. [CrossRef]
45. Babakr, Z.; Mohamedamin, P.; Kakamad, K. Piaget's cognitive developmental theory: Critical review. *Educ. Q. Rev.* **2019**, *2*, 517–524. [CrossRef]
46. Vandenbroucke, L.; Spilt, J.; Verschueren, K.; Piccinin, C.; Baeyens, D. The classroom as a developmental context for cognitive development: A meta-analysis on the importance of teacher-student interactions for children's executive functions. *Rev. Educ. Res.* **2018**, *88*, 125–164. [CrossRef]
47. Venitz, L.; Perels, F. The promotion of self-regulated learning by kindergarten teachers: Differential effects of an indirect intervention. *Int. Electron. J. Elem. Educ.* **2019**, *11*, 437–448. [CrossRef]
48. Karlen, Y.; Hirt, C.N.; Jud, J.; Rosenthal, A.; Eberli, T.D. Teachers as learners and agents of self-regulated learning: The importance of different teachers competence aspects for promoting metacognition. *Teach. Teach. Educ.* **2023**, *125*, 104055. [CrossRef]
49. Jacob, L.; Benick, M.; Dörrenbächer, S.; Perels, F. Promoting self-regulated learning in preschoolers. *J. Child. Educ. Soc.* **2020**, *1*, 116–140. [CrossRef]
50. Oates, S. The importance of autonomous, self-regulated learning in primary initial teacher training. *Front. Educ.* **2019**, *4*, 102. [CrossRef]
51. Sermeno, R. Investigating Head Start Teachers' Science Teaching Attitudes and Efficacy. Master's Thesis, University of Idaho, Moscow, ID, USA, 2022. ProQuest Dissertations & Theses Global.
52. Fusaro, M.; Smith, M.C. Preschoolers' inquisitiveness and science-relevant problem solving. *Early Child. Res. Q.* **2018**, *42*, 119–127. [CrossRef]
53. Gopnik, A. Childhood as a Solution to Explore–Exploit Tensions. *Philos. Trans. R. Soc.* **2020**, *375*, 20190502. [CrossRef]
54. Cremin, T.; Glauert, E.; Craft, A.; Compton, A.; Stylianidou, F. Creative little scientists: Exploring pedagogical synergies between inquiry-based and creative approaches in early years science. In *Creativity and Creative Pedagogies in the Early and Primary Years*; Cremin, R., Ed.; Routledge: London, UK, 2018; pp. 45–60. [CrossRef]
55. Tippett, C.D.; Milford, T.M. Findings from a pre-kindergarten classroom: Making the case for STEM in early childhood education. *Int. J. Sci. Math. Educ.* **2017**, *15*, 67–86. [CrossRef]
56. Shultz, T.R.; Nobandegani, A.S. A computational model of infant learning and reasoning with probabilities. *Psychol. Rev.* **2022**, *129*, 1281–1295. [CrossRef]
57. Walker, C.M.; Bridgers, S.; Gopnik, A. The early emergence and puzzling decline of relational reasoning: Effects of knowledge and search on inferring abstract concepts. *Cognition* **2016**, *156*, 30–40. [CrossRef]
58. Helm, J.H.; Katz, L.G.; Wilson, R. *Young Investigators: The Project Approach in the Early Years*; Teachers College Press: New York, NY, USA, 2023.
59. Adbo, K.; Vidal Carulla, C. Learning about science in preschool: Play-based activities to support children's understanding of chemistry concepts. *Int. J. Early Child.* **2020**, *52*, 17–35. [CrossRef]
60. Dilek, H.; Taşdemir, A.; Konca, A.S.; Baltaci, S. Preschool children's science motivation and process skills during inquiry-based STEM activities. *J. Educ. Sci. Environ. Health* **2020**, *6*, 92–104. [CrossRef]
61. Raven, S.; Wenner, J.A. Science at the center: Meaningful science learning in a preschool classroom. *J. Res. Sci. Teach.* **2023**, *60*, 484–514. [CrossRef]

62. O'Connor, G.; Fragkiadaki, G.; Fleer, M.; Rai, P. Early childhood science education from 0 to 6: A literature review. *Educ. Sci.* **2021**, *11*, 178. [CrossRef]
63. Cantor, P.; Osher, D.; Berg, J.; Steyer, L.; Rose, T. Malleability, plasticity, and individuality: How children learn and develop in context. In *The Science of Learning and Development*; Routledge: London, UK, 2021; pp. 3–54.
64. Aydoner, S.; Bumin, G. The factors associated with school readiness: Sensory processing, motor, and visual perceptual skills, and executive functions in kindergarten children. *Appl. Neuropsychol. Child.* **2023**, *12*, 1–9. [CrossRef] [PubMed]
65. Mavilidi, M.F.; Okely, A.; Chandler, P.; Domazet, S.L.; Paas, F. Immediate and delayed effects of integrating physical activity into preschool children's learning of numeracy skills. *J. Exp. Child Psychol.* **2018**, *166*, 502–519. [CrossRef]
66. Saxena, A.; Lo, C.K.; Hew, K.F.; Wong, G.K.W. Designing unplugged and plugged activities to cultivate computational thinking: An exploratory study in early childhood education. *Asia-Pac. Educ. Res.* **2020**, *29*, 55–66. [CrossRef]
67. Darling-Hammond, L.; Flook, L.; Cook-Harvey, C.; Barron, B.; Osher, D. Implications for educational practice of the science of learning and development. *Appl. Dev. Sci.* **2020**, *24*, 97–140. [CrossRef]
68. Bjerknes, A.L.; Wilhelmsen, T.; Foyn-Bruun, E. A systematic review of curiosity and wonder in natural science and early childhood education research. *J. Res. Child. Educ.* **2024**, *38*, 50–65. [CrossRef]
69. Ravanis, K. Research trends and development perspectives in Early Childhood Science Education: An overview. *Educ. Sci.* **2022**, *12*, 456. [CrossRef]
70. Kastriti, E.; Kalogiannakis, M.; Psycharis, S.; Vavougios, D. The teaching of Natural Sciences in kindergarten based on the principles of STEM and STEAM approach. *Adv. Mob. Learn. Educ. Res.* **2022**, *2*, 268–277. [CrossRef]
71. Larimore, R.A. Preschool science education: A vision for the future. *Early Child. Educ. J.* **2020**, *48*, 703–714. [CrossRef]
72. Saçkes, M.; Trundle, K.C.; Bell, R.L.; O'Connell, A.A. The influence of early science experience in kindergarten on children's immediate and later science achievement: Evidence from the early childhood longitudinal study. *J. Res. Sci. Teach.* **2011**, *48*, 217–235. [CrossRef]
73. Gerde, H.K.; Pierce, S.J.; Lee, K.; Van Egeren, L.A. Early childhood educators' self-efficacy in science, math, and literacy instruction and science practice in the classroom. *Early Educ. Dev.* **2018**, *29*, 70–90. [CrossRef]
74. Nores, M.; Friedman-Krauss, A.; Figueras-Daniel, A. Activity settings, content, and pedagogical strategies in preschool classrooms: Do these influence the interactions we observe? *Early Child. Res. Q.* **2022**, *58*, 264–277. [CrossRef]
75. Guo, Y.; Piasta, S.B.; Bowles, R.P. Exploring preschool children's science content knowledge. *Early Educ. Dev.* **2015**, *26*, 125–146. [CrossRef] [PubMed]
76. Ljung-Djärf, A.; Magnusson, A.; Peterson, S. From doing to learning: Changed focus during a pre-school learning study project on organic decomposition. *Int. J. Sci. Educ.* **2014**, *36*, 659–676. [CrossRef]
77. Hamel, E.; Joo, Y.; Hong, S.Y.; Burton, A. Teacher questioning practices in early childhood science activities. *Early Child. Educ. J.* **2021**, *49*, 375–384. [CrossRef]
78. Sins, P.; de Leeuw, R.; de Brouwer, J.; Vrieling-Teunter, E. Promoting explicit instruction of strategies for self-regulated learning: Evaluating a teacher professional development program in primary education. *Metacogn. Learn.* **2024**, *19*, 215–247. [CrossRef]
79. Pendergast, E.; Lieberman-Betz, R.G.; Vail, C.O. Attitudes and beliefs of prekindergarten teachers toward teaching science to young children. *Early Child. Educ. J.* **2017**, *45*, 43–52. [CrossRef]
80. Park, M.H.; Dimitrov, D.M.; Patterson, L.G.; Park, D.Y. Early childhood teachers' beliefs about readiness for teaching science, technology, engineering, and mathematics. *J. Early Child. Res.* **2017**, *15*, 275–291. [CrossRef]
81. Yıldırım, B. Preschool STEM activities: Preschool teachers' preparation and views. *Early Child. Educ. J.* **2021**, *49*, 149–162. [CrossRef]
82. Dunekacke, S.; Barenthien, J. Research in early childhood teacher domain-specific professional knowledge—A systematic review. *Eur. Early Child. Educ. Res. J.* **2021**, *29*, 633–648. [CrossRef]
83. Kelter, J.; Peel, A.; Bain, C.; Anton, G.; Dabholkar, S.; Horn, M.S.; Wilensky, U. Constructionist co-design: A dual approach to curriculum and professional development. *Br. J. Educ. Technol.* **2021**, *52*, 1043–1059. [CrossRef]
84. Zepeda, S.J. *Professional Development: What Works*; Routledge: London, UK, 2019. [CrossRef]
85. De Boer, H.; Donker, A.S.; Kostons, D.D.; Van der Werf, G.P. Long-term effects of metacognitive strategy instruction on student academic performance: A meta-analysis. *Educ. Res. Rev.* **2018**, *24*, 98–115. [CrossRef]
86. Eberhart, J.; Schäfer, F.; Bryce, D. *Are Metacognition Interventions in School-Aged Children Effective? Evidence from a Series of Meta-Analyses*; OSF: Peoria, IL, USA, 2023. Available online: https://osf.io/preprints/psyarxiv/475br (accessed on 6 May 2024).
87. Donker, A.S.; De Boer, H.; Kostons, D.; Van Ewijk, C.D.; van der Werf, M.P. Effectiveness of learning strategy instruction on academic performance: A meta-analysis. *Educ. Res. Rev.* **2014**, *11*, 1–26. [CrossRef]
88. Philipsen, B.; Tondeur, J.; Pareja Roblin, N.; Vanslambrouck, S.; Zhu, C. Improving teacher professional development for online and blended learning: A systematic meta-aggregative review. *Educ. Technol. Res. Dev.* **2019**, *67*, 1145–1174. [CrossRef]
89. Sims, S.; Fletcher-Wood, H. Identifying the characteristics of effective teacher professional development: A critical review. *Sch. Eff. Sch. Improv.* **2021**, *32*, 47–63. [CrossRef]
90. Kuhn, D. Metacognition matters in many ways. *Educ. Psychol.* **2022**, *57*, 73–86. [CrossRef]
91. Zohar, A.; Ben-Ari, G. Teachers' knowledge and professional development for metacognitive instruction in the context of higher order thinking. *Metacogn. Learn.* **2022**, *17*, 855–895. [CrossRef]

92. Zohar, A.; Lustov, E. Challenges in addressing metacognition in professional development programs in the context of instruction of higher-order thinking. In *Contemporary Pedagogies in Teacher Education and Development*; Weinberger, Y., Libman, Z., Eds.; Springer: Berlin, Germany, 2018; pp. 87–100. [CrossRef]
93. Kraft, M.A.; Blazar, D.; Hogan, D. The effect of teacher coaching on instruction and achievement: A meta-analysis of the causal evidence. *Rev. Educ. Res.* **2018**, *88*, 547–588. [CrossRef]
94. Chalufour, I.; Worth, K.; Clark-Chiarelli, N. *Science Teaching Environment Rating Scale (STERS)*; Education Development Center: Waltham, MA, USA, 2006.
95. Friday Institute for Educational Innovation. *Teacher Efficacy and Attitudes toward STEM (TSTEM) Survey: Development and Psychometric Properties*; North Carolina State University: Raleigh, NC, USA, 2012; Available online: https://www-data.fi.ncsu.edu/wp-content/uploads/2020/11/01153610/T-STEM_FridayInstitute_DevAndPsychometricProperties_FINAL-1.pdf (accessed on 6 May 2024).
96. Balcikanli, C. Metacognitive Awareness Inventory for Teachers (MAIT). *Electron. J. Res. Educ. Psychol.* **2011**, *9*, 1309–1332. [CrossRef]
97. Keselman, H.J.; Huberty, C.J.; Lix, L.M.; Olejnik, S.; Cribbie, R.A.; Donahue, B.; Kowalchuk, R.; Lowman, L.; Petoskey, M.; Keselman, J.; et al. Statistical practices of educational researchers: An analysis of their ANOVA, MANOVA, and ANCOVA analyses. *Rev. Educ. Res.* **1998**, *68*, 350–386. [CrossRef]
98. Enders, C.K.; Tofighi, D. Centering predictor variables in cross-sectional multilevel models: A new look at an old issue. *Psychol. Methods* **2007**, *12*, 121–138. [CrossRef] [PubMed]
99. Gelman, A.; Hill, J. *Data Analysis Using Regression and Multilevel/Hierarchical Models*; Cambridge University Press: Cambridge, UK, 2006.
100. Bates, D.; Mächler, M.; Bolker, B.; Walker, S. Lme4: Linear Mixed-Effects Models Using Eigen and S4. R Package Version 1.1-8. 2015. Available online: http://CRAN.R-project.org/package=lme4 (accessed on 6 May 2024).
101. Braun, V.; Clarke, V. *Thematic Analysis*; American Psychological Association: Washington, DC, USA, 2012. [CrossRef]
102. Cypress, B.S. Rigor or reliability and validity in qualitative research: Perspectives, strategies, reconceptualization, and recommendations. *Dimens. Crit. Care Nurs.* **2017**, *36*, 253–263. [CrossRef] [PubMed]
103. Chen, S.; Geesa, R.; Izci, B.; Song, H. Investigating preservice teachers' science and mathematics teaching efficacy, challenges, and support. *Teach. Educ.* **2022**, *57*, 304–324. [CrossRef]
104. Anthony, C.J.; Ogg, J. Executive function, learning-related behaviors, and science growth from kindergarten to fourth grade. *J. Educ. Psychol.* **2020**, *112*, 1563–1581. [CrossRef]
105. Hessels-Schlatter, C.; Hessels, M.G.; Godin, H.; Spillmann-Rojas, H. Fostering self-regulated learning: From clinical to whole class interventions. *Educ. Child Psychol.* **2017**, *34*, 110–125. [CrossRef]
106. Ismail, N.M.; Tawalbeh, T.E.I. Effectiveness of a metacognitive reading strategies program for improving low achieving EFL readers. *Int. Educ. Stud.* **2015**, *8*, 71–87. [CrossRef]
107. Zohar, A.; Peled, B. The effects of explicit teaching of metastrategic knowledge on low-and high-achieving students. *Learn. Instr.* **2008**, *18*, 337–353. [CrossRef]
108. Dodou, D.; de Winter, J.C. Social desirability is the same in offline, online, and paper surveys: A meta-analysis. *Comput. Hum. Behav.* **2014**, *36*, 487–495. [CrossRef]
109. Başokçu, T.O.; Güzel, M.A. Beyond counting the correct responses: Metacognitive monitoring and score estimations in mathematics. *Psychol. Sch.* **2022**, *59*, 1105–1121. [CrossRef]
110. Arias, J.D.L.F.; Díaz, A.L. Assessing self-regulated learning in early childhood education: Difficulties, needs, and prospects. *Psicothema* **2010**, *22*, 277–283.
111. U.S. Census Bureau. Quick Facts Idaho. 2020. Available online: https://www.census.gov/quickfacts/fact/table/ID/PST045223 (accessed on 6 May 2024).

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Article

Powering Up Preschool Science: A Home–School–Community Partnership to Support Science Learning with a Focus on Emergent Multilingual Learners

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Abstract: All children, including emergent multilingual learners (EMLs), are primed to engage with science from an early age. Yet preschool educators traditionally have not been offered in-depth professional learning (PL) in science, how to teach it effectively to young EMLs, and how to communicate its importance to families. This quasi-experimental study investigated a partnership model designed to engage early educators, children's families, informal science educators, and STEM role models at an informal science learning environment (ISLE)in collaboratively supporting high-quality science experiences for young EML children at school, at home, and in the community. The study examined the effects of a multi-faceted PL program on educators' beliefs and attitudes toward science and their classroom instructional practices. Caregivers were surveyed and interviewed to assess their beliefs and attitudes around early science learning. Results indicated that educators in the treatment condition gained confidence in supporting science with EMLs and showed significant increases in instructional quality relative to comparison classrooms. Caregivers rated themselves as more confident in supporting science with their children. Promoting partnerships between preschools and ISLEs can be an effective way to power up educators' and families' capacities to activate young EMLs' science inquiry, learning, and language development across multiple contexts.

Keywords: early childhood science education; preschool education; children's learning; teacher professional learning; emergent multilingual learners (EMLs); family engagement

1. Introduction

Young children are naturally curious. In their efforts to make sense of the world they live in, they engage with their surroundings in scientific ways: by exploring, asking questions, investigating, and making observations. Indeed, all children—including emergent multilingual learners (EMLs)—are primed to engage with science. Critically, in the early years, high-quality science experiences build a sturdy foundation for children's later learning [1,2]. When children's exploratory play and inquiry is guided by nurturing, engaged adults, it can promote the development of science, technology, engineering, and mathematics (STEM) habits of mind, including persistence, motivation, and flexible thinking [3], while also fostering children's self-efficacy and positive attitudes toward doing and learning science [4]. Moreover, high-quality science experiences provide rich, cognitively challenging content for children to engage with [5]. Yet, one of the key problems facing early childhood science education is that preschool teachers traditionally have not been offered in-depth professional preparation to support their science teaching practice [6,7] or to enact science experiences that incorporate the language-learning approaches that support young EMLs [8].

1.1. Support for Science in the Early Years

While young children are capable of engaging in scientific practices, including making inferences, drawing conclusions, and reasoning about probability, they cannot do it alone [2,9]. When children's science experiences are guided by knowledgeable and engaged adults, including their early childhood teachers and primary caregivers, they build their emerging understanding of science concepts and encourage children's positive attitudes toward doing and learning science, while fostering their collaboration, communication, and creative problem-solving skills [10]. High-quality science experiences in the early years have been linked to children's developing science identity and interests. Research indicates that as early as ages 3 and 4, children develop their STEM interests which, if supported, may persist over time—and even influence their STEM learning trajectories in school and beyond [11–14].

In particular, families have the potential to be powerful facilitators of their children's science learning, inquiry, and interests [15–17]. A growing body of research points to the importance of parent–child conversations—at home and in informal settings—for sparking children's science dispositions and supporting their problem-solving skills and conceptual reasoning [18,19].

1.2. Challenges for Educators and Primary Caregivers in Supporting Early Science Learning

Many teachers of young children lack the knowledge and support they need to promote children's science learning in ways that are aligned with the current vision of a high-quality science education that promotes inquiry, talk, and collaboration [15,20]. In early childhood classrooms, an emphasis on reading and writing can also limit time for these kinds of in-depth science experiences, despite the fact that science can be leveraged as an excellent vehicle for supporting children's early literacy learning [21,22]. EMLs may be further disconnected from the science that does happen in classrooms because many teachers struggle with including these students in ways that connect to the social and academic life of the classroom [23].

For families, even the term *science*—often interpreted as a specific body of knowledge—can be a barrier for caregivers who would otherwise engage their children in inquiry and exploration [24] because they believe they lack the necessary knowledge of science content and how to support learning it with their young children [15,20]. For caregivers with limited economic resources, feelings of inadequacy can be particularly strong; despite valuing learning, their self-efficacy for participating in science may be low [24,25]. Yet, families want to know more about what science their children should be learning, how to best support them, and home activities they can do with simple materials [15]. Families often look to their child's teacher to provide them with support in science and mathematics and have reported a desire to learn from their child's teacher, particularly in STEM content areas [26]. Implicit biases about who does science and who can access the 21st century STEM workforce pipeline may lead families and teachers to steer Black, Latinx, and EML children of all ethnicities away from science and STEM opportunities [27,28]. Teachers may undervalue the potential influence of families on their children's science learning, and families of EMLs especially may feel unwelcome or intimidated in the school environment for any number of reasons [29]. Families experiencing economic hardship, especially those whose home language is not English, often encounter unequal access to culturally sustaining, concrete, and specific information about learning and development in their home languages [30–32]. Despite the clear need for teachers to appropriately engage EMLs in instruction, teacher preparation programs rarely support teachers to work with these learners [33], and educators with more EMLs in their classroom often feel underprepared to meet these students' needs [34]. These factors create an insufficient support system for EMLs that may negatively impact their science and literacy learning, their overall academic achievement, and their enthusiasm for and interest in science [35]. But it does not have to be this way.

1.3. Science and Language: A Natural Fit

Access to concrete science materials and phenomena—a central feature of inquiry—provides a particularly rich context for talk in children's home languages as well as in English [36,37]. Supporting children to engage in inquiry-based science experiences with hands-on materials allows for the inclusion of a diverse range of learners, particularly EMLs. Learning that focuses on *doing* science facilitates language development, particularly when engaged adults encourage children to talk about what they are noticing, describe their observations, and make sense of their findings [3,8]. Research suggests that integrating instructional supports for language learning in the context of children's science experiences promotes language and literacy development in both English and science [36–38]. Science motivates children to use oral language—a precursor to literacy—as they ask questions, talk about their findings, and explain their thinking [36,37]. Promoting strong oral language skills and robust vocabulary knowledge can support children's participation in early science learning by providing them with the words they need to think critically about science concepts and begin to build their understanding of foundational concepts [38–42].

1.4. Forging Strong Partnerships among EMLs' Families and Educators

As a way to power up teachers and families and create a school community that effectively supports all students, including EMLs [43,44], schools must be committed to initiating and supporting culturally and linguistically sustaining, asset-based home–school partnerships. The Dual Capacity-Building Framework for Family–School Partnerships [44] prioritizes building families' and educators' capacities in four key areas: capabilities (skills and knowledge), connections (networks), cognition (shifts in beliefs and values), and confidence (self-efficacy). The Framework addresses common barriers to creating robust home–school partnerships, including families' feelings of being unwelcome or intimidated in the school environment and educators not necessarily viewing family engagement as an essential part of their practice. Teachers can create a welcoming classroom culture and connect families to children's school learning by providing specific ideas for supporting learning at home that are culturally and linguistically responsive and respectful. This enables families to more fully support, encourage, and monitor their children's school learning, to cocreate learning opportunities at home, and to advocate for their children's science learning at school [44].

Much research has been carried out on early childhood learning that links culturally and linguistically responsive teaching and support for children's home language development to child outcomes, including in schools and programs where teachers do not speak the primary home languages of the children in their care [39]. These studies show that when teacher PL incorporates knowledge of effective language teaching strategies for EMLs that include support for the home language, it can improve EMLs' language and literacy outcomes [45,46]. For example, the Personalized Oral Language Learning [47] approach employs a variety of practical strategies for teaching young EMLs that can be applied across content-learning areas [48]. These strategies include focusing on Big Ideas, using intentional messages, asking productive questions, facilitating talk with books and children's work, grouping children intentionally, and partnering with families [48].

1.5. Creating Home–School–Community Partnerships

Connecting children's learning experiences across home, school, and community settings can promote children's science inquiry by enabling them to investigate and talk about related phenomena from different perspectives and with different people [48,49]. For EMLs, these opportunities promote transfer of their conceptual and vocabulary knowledge from one language to another and support bilingualism, self-efficacy, and identity development [50–52]. Extensive research has been carried out on building STEM career interest in middle school and beyond, but far less is known about how to promote the foundational dispositions that will prepare young children for full engagement in the 21st century STEM workforce. We do know, however, that children's informal science experiences at home and in their communities are as important, if not more important, as school is in sparking interest in science, with families playing a critical role in fostering children's early STEM identities [16,53,54]. We also know that high-quality curriculum guidance can be a valuable tool for teachers, especially when it provides suggestions for bridging children's experiences across home and school. SISTEM utilizes the *PEEP and the Big Wide World* digital guide as a way to do this. It includes parallel school and home activities across the three focal topics. Tips for teachers and families on supporting inquiry, and authentic videos of home and school experiences, and all of the other *PEEP* resources are publicly accessible and available in English and Spanish.

1.6. Partnering with Informal Science Learning Environments (ISLEs)

Research shows that ISLE staff and other STEM professionals who reflect children's and families' ethnicities and languages can be powerful role models [55]. Opportunities to interact with "STEM Community Helpers" in different careers who "look like me and speak like me" may have the potential to spark EMLs' STEM interests, promote their confidence, and encourage them to view themselves in similar roles [56]. STEM Community Helpers can also counter some of the biases that families and teachers may hold about who is capable of doing and learning science and promote a shared vision of science inquiry as a vehicle for supporting EMLs' future access to the STEM pipeline [56–58].

Likewise, ISLEs, such as science museums and science centers, provide opportunities for self-directed exploration and inquiry. Families' ISLE experiences and interactions in these settings have been linked to children's early STEM passions for specific objects, topics, and phenomena [16,59]. When families engage in STEM learning with their children in ISLEs—become actively involved; respond to their goals, interests, and wonderings (e.g., *What does this do? How does this work? Why does this happen?*); make connections between STEM phenomena and children's everyday lives; and engage in reciprocal family "science talk"—they can fuel formation of their children's STEM identities [60–63]. Early childhood education staff, who already have strong, trusting relationships with families, can act as a bridge, helping families initiate and sustain relationships with ISLEs, ISLE educators, and local STEM professionals in the community [64–66].

1.7. Theoretical Underpinnings

Our theory of change is grounded in Bronfenbrenner's Ecological Systems Theory [67], which posits that children simultaneously grow and develop within different ecosystems, from the most intimate family and home ecological system, moving outward to educational systems, and then to the larger community. Each system inevitably interacts with and influences the others in every aspect of the child's life. We hypothesize that creating a home–school–community partnership that infuses each level of the learning ecosystem with positive attitudes toward science and opportunities for children to engage with high-quality science practices will shift educators' and families' beliefs and attitudes about science and the value of their own presence in science learning. Taking a sociocultural approach to science, we honor alternative ways of knowing, learning, and interacting around science, and emphasize science identity as a multifaceted construct shaped largely by the implicit and explicit messages children receive from their families, educators, respected community members, and society at large [68–71].

1.8. Overview of Current Study

To address the needs described above, EDC and the Connecticut Science Center (CSC) joined forces with five community-based early childhood programs to develop a program for home-school-community partnership that supports science learning for young EMLs: *Supporting Science Inquiry, Interest, and STEM Thinking for Young Dual Language Learners* (SISTEM). In this paper, we describe a quasi-experimental pilot study of the SISTEM program for home–school–community partnerships to support science learning for young EMLs that uses a mixed-methods approach to address the following research questions:

RQ1. Is SISTEM participation associated with preschool educators' self-efficacy in science teaching and in engaging EMLs and their families in science?

RQ2. Is SISTEM participation associated with increased quality of preschool educators' science teaching?

RQ3. Is SISTEM participation associated with preschool caregivers' positive beliefs and attitudes about supporting their children's science learning and interest in STEM?

2. Materials and Methods

2.1. Setting

This study took place in Hartford, Connecticut, in partnership with CSC and five community preschool programs, all of which serve a diverse population of children and families that includes EMLs. The city has the lowest median income and the highest poverty rate in the state [72] in the areas in which the programs are located, and community members deal with high rates of unemployment, violent crime, and food insecurity [73] with 49% of residents living below the federal poverty line and only 38% earning high school degrees. Yet, this community is rich in cultural funds of knowledge, skills, abilities, resources, strengths, and aspirational, navigational, social, linguistic, and familial capital [74–76].

The CSC was an ideal project partner and central setting for this project as its aim is to bring to life its mission statement, "to develop the minds of future thinkers and inventors who will compete in the global marketplace for technology and innovation", for all the city's children, including its very youngest. To do so, CSC recruits local STEM organizations and professionals who facilitate science and engineering activities for families and act as community STEM role models.

2.2. Post-Pandemic Challenges

This study occurred during the 2022–2023 school year. While we were able to meet in person for the PL sessions and the "I Love Science!" events held at CSC, many programs were operating fewer classrooms than they had pre-COVID-19 due to staff shortages. Many families were on waitlists to enroll, but programs were struggling to hire staff. Additionally, some programs had continued their COVID-19-related restrictions on allowing outside guests and families into schools. Given these limitations and the continued uncertainty of visitor policies, we held some components of the program virtually.

2.3. Program: The SISTEM Model

The full SISTEM model was organized around three topics of study: Water in the fall, Ramps in the winter, and Shadows in the spring. It included three PL instructional sessions for educators and program staff, collectively referred to as the Inquiry Institute; six virtual professional learning community (PLC) meetings customized to meet the needs of educators and staff at individual programs; three PE collaborative workshops, mainly held remotely but with two programs opting to independently organize and facilitate the third one onsite; and three "I Love Science!" events held at CSC in fall, winter, and spring. These all-inclusive events, held at the beginning, middle, and end of the program year, were designed to bring all project participants and teams together with their own families to experience and engage with the exhibits and a variety of activities facilitated by ISLE educators and local STEM Community Helpers. Resources included three classroom science kits for participating classrooms, one for each topic of study, and three smaller topic-specific kits for each participating family. Educators and families also received information and guidance for using digital resources to support children's home, school, and community explorations of each topic.

The most central digital resource was the *PEEP and the Big Wide World* suite of online materials, which included guidance for facilitating Water, Ramps, and Shadows experiences with young children at home and school; tips for teachers and families on supporting inquiry; and a wealth of short videos illustrating authentic classroom and family explorations of these topics. All *PEEP* resources are publicly accessible on computers, tablets, and smartphones and available in English and Spanish. We also created digital resources, such as "unboxing" videos for families, providing suggestions for how families might use the materials in the home science kits to support topical explorations with their children (see Table 1 for the program components). All of these events and resources worked toward advancing six program objectives, described in Section 2.4.

Table 1. SISTEM program components.

	Water	Ramps	Shadows
Inquiry Institute	PL Session 1 (6.5 h). Tools for language-rich inquiry during a Water study. Immersive experiences.	PL Session 2 (6.5 h) Tools for language-rich inquiry during a Ramps study. Immersive experiences.	PL Session 3 (6.5 h). Tools for language-rich inquiry during a Shadows study. Immersive experiences.
Professional Learning Communities (PLCs)	Two Zoom meetings: 1. Classroom practice and *PEEP* resources. 2. Family engagement.	Two Zoom meetings: 1. Classroom practice and *PEEP* resources. 2. Family engagement.	Two Zoom meetings: 1. Classroom practice and *PEEP* resources. 2. Family engagement.
Parent–Educator (PE) workshops	One virtual session. Home science kit. Spanish and English.	One virtual session. Unboxing video. Home science kit. Spanish and English.	Three virtual sessions and two onsite sessions. Unboxing video. Home science kit. Spanish and English.
CSC "I Love Science!" events	Focus Families, educators, program staff and their families. STEM Community Helpers.	Focus Families, educators, program staff and their families. STEM Community Helpers.	Focus Families, educators, program staff and their families. STEM Community Helpers.

2.4. Program Objectives

All program objectives were focused on building adults' capacity to support early science inquiry and to forge relationships across home, school, and community, thus creating a web of supports for promoting all children's (with a focus on EMLs) science and language learning across contexts.

2.4.1. Objective 1: Provide Educators with Guidance, Resources, and Support for Engaging Children in Rich Science Inquiry and Learning around Three Compelling Topics (Water, Ramps, and Shadows) That Can Be Explored across Contexts

A team of early science and teacher educators from EDC and CSC implemented and facilitated three robust full-day PL sessions—the Inquiry Institute—that allowed for a gradual, integrated introduction of pedagogical content and strategies for promoting children's inquiry, talk, and vocabulary through direct experiences (Session 1), interactive books and readings (Session 2), and supporting documentation and children's representations (Session 3). Based on our ecological systems approach and the goal to infuse each level of the learning ecosystem with positive attitudes toward science, it was important to offer this PL to *all* educators working in each participating classroom, including lead teachers, assistant teachers, support staff, and curriculum specialists. To make it possible for full teaching teams to participate, sessions were held on Saturdays.

Each session included the following elements: a reflection discussion on how educators had applied learning from the previous session (Sessions 2 and 3); an introduction to the science content relevant to the topic; adult immersive experiences of inquiry into the topic; strategies for facilitating talk about the topic across the inquiry cycle; representations of the topic from authentic classrooms, including children's work, educator documentation, and *PEEP* videos; an overview of the *PEEP and the Big Wide World* teacher and family resources available for that topic; and time for collaborative planning, using a planning form we developed that was aligned to the teachers' current planning form and emphasized integration across the Early Learning and Development Standards [77] (see Figure 1). At PL sessions 2 and 3, we shifted the adult immersive experiences to incorporate five or six investigation stations that educators rotated through to more effectively scaffold their use of the *PEEP* resources. During Sessions 2 and 3 we also moved the planning section to earlier in the day and then revisited planning at the end of the session to devote more time to planning for classroom implementation. Assessment of children's learning was emphasized in Session 3; as part of the reflection discussion, we assisted educators in creating documentation panels to help make children's science learning visible to families.

SISTEM Planning Form
Planning for Shadows

Teacher(s)			
Big Idea (aligned ELDS)			
Intentional Message			
Target Vocabulary	English		Home Language
Learning Goals	Cognition		
	Language Literacy		
	Math		
	Soc/Emotional		
	Physical Health		
	Creative Art		
Family Engagement Plan			
Identify the POLL Strategies that are supported	Big Idea and Intentional Message Targeted Vocabulary Small group supports		Songs and chants Documentation of explorations Anchor Text

Describe the Experience	**How will the Teacher support inquiry? What will they say/do?**
Materials or changes to the environment	
Describe the Experience	**How will the Teacher support inquiry? What will they say/do?**

Figure 1. SISTEM planning form for Shadows explorations.

2.4.2. Objective 2: Support Educators' Classroom Pedagogy and Family Engagement Practices with Individualized Scaffolding Based on Each Program's Goals, Strengths, Needs, and Interests

Educators at each of the five programs, including lead teachers and assistant teachers, were invited to engage in six collaborative program-specific PLC meetings across the school year (two after each Inquiry Institute session) to support their transition from theory to practice and their capacity and confidence in applying the science pedagogy (PLC meeting 1) and family partnership practices (PLC meeting 2) introduced at the PL sessions. These meetings were designed to be program-specific in order to meet the needs of each of the five programs, which varied broadly across multiple indicators (e.g., diversity of educators, staff, and families; educators' prior experiences with science teaching; degree of current family partnership commitments). A highly experienced EDC coach facilitated the meetings, offering two options for attendance to each program to be responsive to individual program schedules, increase educator participation, and address the specific needs of program staff in dealing with post-COVID-19 stressors.

PLC meetings focused on classroom implementation prioritized opportunities for educators to share "roses and thorns" as they implemented new science and language support strategies with children in their classrooms. The family-engagement-focused PLC meetings provided opportunities for educators to discuss their current interactions with families, share ways of deepening reciprocal relationships around science and language with a focus on EMLs' families, and supported planning the upcoming PE workshop. For example, the initial family-engagement-focused meeting laid the groundwork for reaching out to and engaging families in the project and begin the process of learning about families' routines, typical family activities, and primary home languages. In subsequent meetings, the coach introduced a concept map of potential topics educators might discuss with families and helped them select ones they identified as relevant to their own families' strengths, needs, and interests. At the final PLC meeting, the EDC coach organized educators into separate meetings according to the degree to which they felt comfortable taking ownership of the event and facilitating the final PE workshop, either independently and in person at their program, virtually with support from the EDC coach, or virtually with the EDC coach facilitating most of the meeting.

2.4.3. Objective 3: Bring Families and Educators Together for Collaborative Inquiry-Based Learning, Discussions about the Science Children Are Doing at School, and Joint Planning for Aligned Home and Family Experiences

Educators were asked to invite up to four multilingual families (referred to as "Focus Families") to participate in a series of three collaborative Parent/Educator (PE) Workshops (one per topic). The PE workshops were designed to strengthen educators' capacity to engage, educate, and power up EMLs' families around early science and language and to provide a venue in which EMLs' primary caregivers would feel confident and comfortable about engaging with educators around science, language, and their child's learning. All PE meetings were held in English and Spanish with simultaneous interpretation. EDC staff facilitated discussions that incorporated the *what*, *how*, and *why* of early science learning, introduced concept and inquiry-support practices that adults could apply across settings, and offered an overview of books and *PEEP* digital resources specific to the topic at hand.

Educators and parents also interacted directly in breakout rooms, including significant time for educators and primary caregivers to share photos, videos, and stories of children's home and school explorations with one another. The time allotted for these conversations increased at each subsequent meeting as educators became more comfortable guiding the discussions. All PE meetings were scheduled with input from program directors and educators to ensure that they were responsive to both educators' and parents' availability.

2.4.4. Objective 4: Facilitate Innovative Adult Learning Experiences That Bring All Participating Adults (Educators and Parents) Together with Their Families for Informal Science Experiences

EDC and CSC staff hosted three "I Love Science!" events, held at the CSC, that were the backbone of the SISTEM model and brought together Focus Families, program educators and staff, EDC and CSC staff, and all of their families for science exploration and learning. At each event, Focus Families and program staff received "passports" in English and Spanish to orient them to the science center and exhibits specifically designed for young children; despite the CSC's close proximity to the five programs, only a small percentage of educators and families had previously visited the center. Program staff and families collaboratively explored the center's exhibits, including those related to the topics being explored at school and at home. Supported by ISLE educators, staff and families interacted at a giant stream table and water play area (Event 1), activities to build their own roller coaster and race cars down ramps (Event 2), and a weather broadcasting simulation and shadow puppets experience (Event 3).

The third "I Love Science!" event was a culminating SISTEM celebration. Participating staff and families were encouraged to explore the entirety of CSC with their families. A special event space was set up for Fartner Families and program staff to enjoy a slideshow of photos taken across the year and to view and discuss the documentation panels educators had created of Ramps and Shadows explorations. Everyone shared a celebratory lunch hosted by the CSC.

2.4.5. Objective 5: Activate a STEM Community Helper Model with CSC's Hispanic STEM Career Professionals Who Can Broaden Families' and Educators' Awareness of STEM Careers

The CSC "I Love Science!" events provided a context for activating the STEM Community Helpers model and broadening children's and adults' awareness of STEM careers and the people who have them. At each event, a diverse group of local STEM professionals who hold STEM-related positions at several local companies facilitated investigations compelling to preschoolers, including engineering straw rockets and sink-and-float explorations (Event 1), a Junior Fire Marshall demonstration to learn more about how STEM Community Helpers' roles connect to STEM (Event 2), and space-related programs and activities as part of CSC's Space Day (Event 3).

2.4.6. Objective 6: Employ Innovative Digital Technologies and Resources in English and Spanish to Support Initiating, Strengthening, and Sustaining Home–School–Community STEM Connections

For this objective, we created several digital resources, including Google sites specific to educators and families, unboxing videos, and a digital newsletter. A teacher-facing Google site and a companion family site (in English and Spanish) were designed and developed to be active, with evolving resources where educators and families could easily access all the Water, Ramps, and Shadows resources as they were added throughout the year. After the launch of each new topic, the sites were updated with supporting materials, including photos, videos, tip sheets, and links to resources. The unboxing videos were created to support families' engagement with the home science ramps and shadows kits. Each video featured a CSC informal science educator who previewed and described the home science kit materials (in English and Spanish) and demonstrated multiple ways of using them to support children's inquiry. The home science kits and the digital newsletter included QR-coded links to the unboxing videos, making them easily accessible to families. We also developed a bilingual digital newsletter aimed at both educators and families that provided reminders of program events, additional information related to each topic of study, links to resources, photos from homes and classrooms, and further guidance for facilitating children's inquiry. The joint newsletter enabled parents and educators to see the direct connections between the home and school resources. The newsletter was distributed to educators, who then delivered digital or hard copies to families. The newsletters were also added to the educator and family Google sites. Finally, we created bilingual family-friendly flyers to notify families of the CSC "I Love Science!" events.

2.5. Research Design

2.5.1. Recruitment

To support successful implementation and buy-in, we met with program administrators and support staff the spring before implementation to explain the project in detail and describe program and educator expectations and project components. We asked participating directors to sign a commitment form specifying that they will attend monthly check-in meetings with the SISTEM team and designate a "SISTEM liaison" (e.g., curriculum specialist, family engagement coordinator) to participate in the program.

After directors signed the commitment form, the research team met with educators to explain the project, answer questions, and invite participation. The team recruited 22 classrooms; 11 were asked to be in the treatment condition (Group 1) and 11 in the comparison, education-as-usual condition (Group 2). Treatment classrooms engaged in SISTEM PL in the 2022–2023 school year, and comparison classrooms engaged in SISTEM PL the following school year. Note: We did not randomly assign classrooms to treatment or comparison groups, as this was a quasi-experimental study, and directors often requested the classroom's condition (e.g., one teacher was scheduled for maternity leave and could not attend all PL sessions, so she was assigned to the comparison group). All educators from participating classrooms (lead teachers and assistant teachers) were invited to participate and were asked to complete a consent form. Among treatment classrooms (henceforth referred to as *SISTEM classrooms*), 23 educators consented to participate in the first year of the SISTEM PL.

Throughout the year, participation was significantly impacted by teacher turnover and program restructuring. In late fall, one comparison classroom was redesignated as an infant–toddler classroom and so could no longer participate; we recruited another comparison classroom to replace it, but the educators from this classroom also ultimately left the program. Midyear, an SISTEM classroom was also redesignated as an infant–toddler classroom and could no longer participate, and an additional teacher from an SISTEM classroom and a comparison classroom left their programs and could no longer participate. The SISTEM PL was well under way at this point; therefore, these classrooms could not be replaced. In addition, two assistant teachers from SISTEM classrooms and two assistant teachers from comparison classrooms left their positions midyear, although the lead teachers from these classrooms continued their participation.

2.5.2. Participants

After the attrition described above, there were a total of 9 SISTEM classrooms with 16 participating educators, and 11 comparison classrooms with 13 participating educators. Of these 29 total educators, 27 provided information about their years of experience, education, and demographics. Average years of experience in early childhood education was similar across groups: 6.85 years (SD = 6.78) for SISTEM educators, and 7.92 years (SD = 7.93) for comparison educators. In both groups, about half the educators reported that they were able to communicate in a language other than English (most often Spanish): 58% of SISTEM classroom educators and 54% of comparison classroom educators. A total of 42% of SISTEM classroom educators had bachelor's degrees, 24% had associate's degrees, 17% had some college experience, and 17% had a high school diploma or GED. Comparison classroom educators had a roughly similar distribution of education: 7% had graduate degrees, 42% had bachelor's degrees, 22% had associate's degrees, and 29% had some college experience. Three SISTEM educators and one comparison classroom educator were male; the rest were female.

Once all educators were recruited, SISTEM classrooms invited up to four multilingual families to serve as Focus Families. Across the nine SISTEM classrooms, educators recruited a total of 24 Focus Families. A majority of Focus Families spoke either Spanish or a mix of Spanish and English at home; one family spoke French and Togo.

2.6. Instruments and Analysis

2.6.1. Surveys

To assess participants' perceptions of program impacts after completion of the program, we developed survey scales for Focus Families and SISTEM educators to rate their beliefs and attitudes related to science before and after participating in SISTEM. Educators were asked to rate nine items related to their beliefs about the importance and value of early science learning and their comfort, confidence, and excitement about teaching science and engaging EMLs and their families in science. Parents rated two items related to their beliefs about the value of science for their child and their awareness of STEM careers, and five items related to their comfort, confidence, and excitement about engaging in science learning with their child. All items were rated on a six-point scale (from "very low" to "very high"). Participants were asked to rate each item twice: retrospectively reporting on their beliefs and attitudes *before* participating in SISTEM, and their current beliefs and attitudes *after* having participated in SISTEM.

2.6.2. Classroom Observations

To evaluate the quality of science teaching practices, we used a modified version of an observation protocol called the Science Teaching and Environment Rating Scale (STERS) [78]. The STERS is a classroom observation tool designed to measure the quality of teacher–child interactions, the environment, and teachers' planning and assessment practices related to science teaching and learning in the preschool classroom. Teachers are asked to lead a science activity or exploration of their choosing. Observers code eight items on a four-point scale (1 = deficient, 2 = inadequate, 3 = adequate, and 4 = exemplary) based on the extent to which teachers do the following: (1) create a physical environment for inquiry and learning, (2) facilitate direct experiences to promote conceptual learning,

(3) promote use of scientific inquiry, (4) create a collaborative climate that promotes exploration and understanding, (5) engage in extended conversations, (6) build children's vocabulary, (7) plan in-depth investigations, and (8) assess children's learning (for more information about these items, see [79]). The original observation protocol was intended to be conducted in person and to include interviews with teachers before and after the observation to evaluate their thinking about planning and assessment. We modified the protocol to be used for video observations, eliminating both these interviews and two items that would have been assessed during an interview ("*Plan in-depth investigations*" and "*Assess children's learning*"). Additionally, for the item "*Create a physical environment for inquiry and learning*", we did not include indicators related to aspects of the classroom environment that could not be observed on camera (e.g., availability of science books related to the topic, use of displays), instead focusing on observable use of materials.

2.6.3. Research Team Informal Observations

Research staff attended and observed all program meetings and events. Staff convened weekly research meetings to review and discuss field notes, observations, interviews from SISTEM events, discussions with educators and Fartner Families, photos and videos shared by educators and families, and educator reflections of SISTEM's impact on their practices shared at the last PLC.

2.7. Procedures

In the 2022–2023 school year, some early childhood programs in the study continued to have COVID-19- and illness-related concerns (such as flu and RSV), particularly around outside visitors in classrooms. For this reason, classrooms were provided with iPads and tripods, and educators were asked to video-record their classroom science instruction in lieu of in-person observations. In the fall, before the start of the PL sessions, we asked both SISTEM and comparison classrooms to record a video of any science activity or experience, on any science topic, aiming for 10–20 min of footage. In the spring, after the completion of SISTEM PL activities, we asked both SISTEM and comparison classrooms to record a video of a science activity focusing on the topic of Shadows, again aiming for 10–20 min of footage. Educators uploaded and shared their video recordings via secure sharing, and we stored the recordings on a secure storage site. We received complete fall and spring recordings for 12 classrooms (6 SISTEM and 6 comparison). Although some videos included assistant teachers, all observed activities were led by lead teachers. A member of the research team, who is an STERS master coder, trained an external evaluator on the modified STERS protocol. The trainer and the external evaluator independently coded three observation videos to ensure that the external evaluator was reliably scoring according to the STERS training guidelines. The evaluator then scored all video observations.

We asked SISTEM educators and Focus Families to complete surveys in the spring after the completion of SISTEM activities. A total of 11 SISTEM educators and 9 Focus Family caregivers completed the survey. We asked all SISTEM educators to participate in one of several reflective conversations over Zoom after the completion of SISTEM PL activities. Finally, we conducted four interviews with Focus Family caregivers to gain greater insight into their experiences.

Attrition and Fidelity

Of the 23 educators who originally signed on to participate in SISTEM, seven left their programs or were moved to different positions and could no longer participate. The remaining 16 had the opportunity to participate in three PL sessions, six PLC meetings, three PE meetings, and three CSC events. Eighty-one percent attended two or three PL sessions, all attended at least four PLC meetings, 88% attended at least one PE meeting, and 88% attended at least one CSC event.

2.8. Analysis Plan

To address our research questions, we conducted quantitative analyses and synthesized reflective conversations with educators and informal observations. Quantitative methods are described here. To address RQ1, we conducted paired *t*-tests on SISTEM educators' ratings of their beliefs and attitudes before and after participation in SISTEM. Using data from both SISTEM and comparison classrooms, we conducted a series of regression analyses on each science teaching practice, regressing the quality of spring science teaching quality on fall science teaching quality and participation in SISTEM. To further explore changes in teaching practice, we also conducted paired *t*-tests on each science teaching practice for SISTEM and comparison teachers. To address RQ2 and RQ3, we conducted paired *t*-tests on caregivers' ratings of their beliefs and attitudes before and after participating in SISTEM.

3. Results

3.1. Impact on Educators' Self-Efficacy

To understand changes in educators' sense of self-efficacy related to their science teaching practice and engaging with EMLs and their families around science learning, we conducted paired *t*-tests comparing educators' retrospective ratings of their feelings before SISTEM participation with their ratings of their current feelings (See Table 2). Eleven educators completed "before" and "after" ratings. All ratings significantly increased except for one ("*Belief that science is important for children's future careers*"), which had only a marginally significant effect, $t(10) = 2.19$, $p = .054$.

Table 2. Educators' science beliefs and attitudes.

Science Beliefs and Attitudes	Before SISTEM M (SD)	After SISTEM M (SD)	Difference (After–Before)	SE Mean	t (df = 10)
Confidence in planning science experiences for children	3.09 (1.14)	5.00 (0.78)	1.91	0.32	6.06 ***
Belief that science is important for children's future careers	4.27 (0.79)	5.00 (1.10)	0.73	0.33	2.19 †
Belief in the importance of giving children opportunities to see people who look like them in science careers	3.55 (1.37)	4.64 (1.29)	1.09	0.32	3.46 **
Excitement to do science in the classroom	3.64 (1.21)	5.18 (0.98)	1.55	0.34	4.54 **
Confidence in supporting children's language development through science	3.73 (0.65)	4.91 (0.70)	1.18	0.18	6.50 ***
Confidence in supporting EMLs during science experiences	3.64 (1.12)	4.82 (0.75)	1.18	0.18	6.50 ***
Comfort in asking productive questions during science experiences	3.36 (1.21)	4.82 (0.60)	1.46	0.34	4.28 **
Interest in engaging all families in science learning	3.27 (1.42)	4.91 (1.04)	1.64	0.31	5.29 ***
Confidence in engaging EML families in science learning	3.09 (1.45)	4.82 (0.98)	1.73	0.41	4.25 **

† $p < .10$, ** $p < .01$, *** $p < .001$.

3.2. Impact on Educators' Science Instructional Practice

To understand how SISTEM impacted educators' science teaching practice, we compared the quality of SISTEM and comparison educators' science teaching practice, as measured by six items of the STERS, in fall and spring. In the fall, educators were free to lead a science activity on a topic of their choosing. Among the 12 classrooms with complete fall and spring observation data, eight educators led activities related to mixing and reactions (e.g., mixing paints of different colors, mixing oil and water, mixing baking soda and vinegar), two led activities about pumpkins (cutting it open and looking at its parts), one led an activity about magnets, and one led an activity about capillary action on a paper towel. In the spring, all educators were asked to lead an activity related to or an exploration of shadows. Descriptive statistics are presented in Table 3.

Table 3. STERS descriptives for SISTEM and comparison classrooms.

	SISTEM Classrooms (n = 6)		**Comparison Classrooms (n = 6)**	
Science Teaching Practice	**Fall M (SD)**	**Spring M (SD)**	**Fall M (SD)**	**Spring M (SD)**
Create a physical environment for inquiry and learning	3.17 (1.33)	2.83 (0.41)	2.83 (0.98)	2.67 (1.51)
Facilitate direct experiences to promote conceptual learning	2.33 (1.21)	3.17 (0.75)	2.50 (1.23)	3.00 (1.55)
Promote use of scientific inquiry	2.00 (0.89)	3.00 (0.00)	2.33 (1.03)	2.17 (0.98)
Create a collaborative climate that promotes exploration and understanding	2.00 (0.89)	2.33 (0.52)	2.33 (1.03)	2.17 (0.98)
Engage in extended conversations	2.00 (0.89)	2.50 (0.84)	2.33 (1.03)	2.50 (1.23)
Build children's vocabulary	1.33 (0.52)	2.00 (0.00)	1.67 (0.82)	1.83 (0.41)

Regression analyses indicated that SISTEM (Treatment) was significantly associated with spring scores related to educators' ability to *"Promote use of scientific inquiry"* (See Table 4). The estimated coefficient for this effect indicates that, on average, SISTEM was associated with a one-point increase in spring STERS scores relative to comparison classrooms, controlling for fall scores. No other science teaching practices were significantly associated with SISTEM participation.

Table 4. STERS regression analyses.

Dependent Variable	**Independent Variable**	**B (SE)**	**β**	***t***	***p***
Create a physical environment for inquiry and learning	Fall Score Treatment	0.65 (0.23) –0.05 (0.50)	0.69 –0.02	2.82 –0.10	.020 .924
Facilitate direct experiences to promote conceptual learning	Fall Score Treatment	0.65 (0.25) 0.28 (0.56)	0.65 0.12	2.58 0.49	.030 .637
Promote use of scientific inquiry	Fall Score Treatment	0.50 (0.17) 1.00 (0.31)	0.59 0.66	2.90 3.23	.018 .010
Create a collaborative climate that promotes exploration and understanding	Fall Score Treatment	0.61 (0.18) 0.37 (0.32)	0.76 0.26	3.37 1.14	.008 .283
Engage in extended conversations	Fall Score Treatment	0.86 (0.22) 0.29 (0.40)	0.80 0.15	3.86 0.72	.004 .492
Build children's vocabulary	Fall Score Treatment	0.36 (0.23) 0.29 (0.30)	0.47 0.29	1.55 0.96	.156 .363

To further explore changes in science teaching practices, we conducted paired t-tests, comparing fall and spring scores for SISTEM educators and comparison educators. Paired t-tests revealed that comparison educators did not significantly increase in any teaching practices from fall to spring, although they did marginally increase in scores related to "*Facilitate direct experiences to promote conceptual learning*", $t(5) = 2.24$, $p = .076$. SISTEM educators, however, significantly increased their scores in both "*Promote use of scientific inquiry*", $t(5) = 2.74$, $p = .041$, and "*Build children's vocabulary*", $t(5) = 3.16$, $p = .025$.

Educators Learned and Applied Strategies for Supporting Children's Science Inquiry and Gained Confidence in Supporting Science with Children in Classrooms

During reflective conversations, all educators shared that they had shifted their pedagogy directly related to science teaching and learning. One of the biggest changes mentioned was the use of the Big Idea/Intentional Message to drive the classroom curriculum and to motivate more extended investigations. One educator said, "Science used to just be in the science area, but we have learned how to make it come alive in the classroom. The children are so excited, the interest just explodes. Letting them investigate topics over time really helps them think and learn". Educators noted a shift from more didactic practices, such as providing facts and demonstrating or leading experiments, to a more scaffolded approach that supported children to think, wonder, and form new ideas through intentionally planned materials, experiences, and interactions. As one educator said, "It made me take a step back and allow the children to take the lead instead of me just giving directions; now I know how to encourage them to explore and investigate".

As Science Big Ideas moved to the forefront of educators' planning, learning goals needed to be aligned to all domains of the state's Early Learning and Development Standards. SISTEM created and provided educators with crosswalks and supportive documents to strengthen their curriculum planning. This immersive approach was embraced by educators as they planned and implemented experiences that provided rich, connected learning. Educators identified learning goals, such as "*measurement and data*" as children checked the changing size of shadows and recorded their results, "*use of rich, expressive language*" and "*use of new vocabulary*" as children talked about what they were doing and how they created a shadow to look like an object and changed its size, and "*approaches to learning*" such as pride in their accomplishments, persistence, problem-solving skills, creativity, and fine motor skills.

Educators also reflected on meeting the needs of the EMLs in their classrooms. One teacher noted, "This approach has allowed me to meet the needs of all of the children in my classroom. Most of the learning goals in math, cognition, language/literacy, fine motor development, and even the creative arts can be supported in a dynamic and interactive way. The children are so engaged, and seeing them apply their skills as they investigate these topics has been so exciting".

3.3. Impact on Caregivers' Understanding of the Importance of Science Learning and Awareness of STEM Careers

After participating in SISTEM, caregivers rated their understanding of how science can help their child develop language skills and their awareness of potential STEM careers before and after participation. Responses indicated that both increased significantly. On average, parents' ratings of their understanding and awareness of STEM careers changed from "Somewhat low" (a rating of 3 on the 6-point scale) to "High" (a rating of 5 on the 6-point scale; See Table 5).

Table 5. Caregivers' science beliefs and attitudes.

Science Beliefs and Attitudes	Before SISTEM M (SD)	After SISTEM M (SD)	Difference (After–Before)	SE Mean	t (df = 9)
Understanding of how science can help my child develop language skills	2.80 (1.48)	4.90 (0.74)	2.10	0.50	4.16 *
Awareness of STEM careers that my child might be interested in someday	3.10 (1.52)	5.00 (0.82)	1.90	0.43	4.39 *

* $p < .01$.

3.4. Impact on Caregivers' Confidence in Engaging Their Children in Science and Working with Their Child's Teacher to Support Their Child's Learning

Following the SISTEM program, caregivers rated their comfort and confidence in supporting their child's science learning as having significantly increased from before their participation in the project (See Table 6). The biggest change as rated by caregivers was in their confidence around working with their child's teacher to support their child's science learning. Individual interviews confirmed this sentiment; as one parent noted, "I love how the teacher shared about the science children were doing at school, because then I could explore some of the same things with him at home and send [the teacher] pictures too". Another caregiver said, "I am closer to the teacher just because of all those workshops and the times where I would go to the science center and [my child's] teacher would be there as well".

Table 6. Caregivers' confidence engaging children in science.

Science Beliefs and Attitudes	Before SISTEM M (SD)	After SISTEM M (SD)	Difference (After–Before)	SE Mean	t (df = 9)
Interest in exploring science with my child	3.30 (1.16)	5.00 (0.94)	1.70	0.34	5.08 **
Belief that exploring science is a fun way to spend time with my child	3.60 (1.17)	5.20 (1.14)	1.60	0.45	3.54 **
Confidence that I play an important role in supporting my child's science learning	3.40 (1.27)	5.20 (0.63)	1.80	0.39	4.63 **
Confidence in working together with my child's teacher to support my child's learning	3.20 (1.23)	5.30 (0.68)	2.10	0.41	5.16 **
Comfort in visiting the Connecticut Science Center with my child	3.50 (1.58)	5.40 (0.84)	1.90	0.57	3.24 *

* $p < .05$, ** $p < .01$.

3.4.1. Families Interacted with Their Children around Science at Home and in the Community and Were Empowered to Share Their Explorations with Their Children's Teachers and Others

The documentation obtained of families interacting during their home explorations and data from the PE meetings indicated that small moments of family connection have the potential to be valuable learning opportunities for children and their parents. In some cases, parents described how they had observed a child's knowledge and skills in action that they had not noticed before and became notably excited at seeing what curious and capable young scientists and problem-solvers their children were becoming. During the first virtual PE meeting, one parent was so delighted by her child's engagement in water explorations that she spontaneously shared her screen to show and describe a video of her daughter at the kitchen sink exploring water with the cups, baster, clear tubing, and funnel from the home science (Water) kit. During a breakout session at the second PE meeting, a parent who appeared hesitant to speak up in the full group shared during a breakout session with her child's teacher (in Spanish): "At home [my child] rolls his cars and his balls down everything. He thinks the bigger balls and cars with bigger wheels go faster. I use vocabulary with him too. What happened with this ball? How much more does it weigh? Which one is the smallest? And yesterday we talked about how the one that has more weight goes farther than the other ones".

The videos families shared that included interactions between and among family members were particularly revealing. After the third PE meeting (focused on Shadows), a parent shared a video of her and her daughter discussing their own shadows outdoors as they headed to their car for the trip to school. In the video, the child moves excitedly around her mom in an effort to find a position that allows both of their shadows to appear distinctly ("Mama, get off my shadow!"). The mother then encourages her child to stand next to her so that both of their shadows can be seen distinctly. This prompts a conversation about their "bigger" and "smaller" shadows and how the relative sizes of their shadows change when they move in relation to one another. Mom then playfully encourages the child to try to escape from her shadow, and the child excitedly runs toward their car, simultaneously observing her shadow.

3.4.2. Families, Educators, and School Staff Gained Familiarity with CSC and Its Exhibits, Offerings, and Resources, and Explored Connections to STEM Careers

The three "I Love Science!" events brought a substantial number of SISTEM Focus Families, SISTEM educators and program staff, and educators' families to CSC. Extended families attending the events included grandparents, aunts, uncles, and cousins; one program director was accompanied by three generations of her own family, including her infant great-granddaughter. The "passports" in English and Spanish distributed at Events 1 and 2 and the map of CSC exhibits and activities provided at Event 3 (all in English and Spanish) empowered families to navigate CSC independently and to focus on exhibits and activities related to the SISTEM topics and relevant career connections (e.g., the Build a Roller Coaster exhibit for Ramps, the Forecast the Weather station for Shadows). In addition, CSC had added signage in Spanish and English to two exhibit galleries in 2023, along with general Spanish-language building signage for navigating the center, which allowed for even more family agency in interacting with the exhibits and experiences. Being able to navigate CSC in self-selected groups of families and educators also enabled participants to engage with other exhibits of interest to them that may not have been directly connected to the topics being explored at school and at home, piquing their curiosity and motivating them to return for another visit.

After the first CSC event, families began asking about the benefits of membership, attending special CSC events, and making return visits. Educators also made return visits with their own families, and one partner preschool program brought all their students on their first ever schoolwide field trip to CSC.

Having STEM Community Helpers at the events facilitating additional preK-level activities added value to participants' experiences. For children, families, and educators alike, it was inspiring to interact with adults in STEM roles who represented their own ethnicity, culture, and language. Several SISTEM parents reported that normally they would just walk by activities facilitated by science center staff because they could not understand the activity guidance provided. The presence of STEM Community Helpers who were native Spanish speakers enabled these families to participate in the activities and interact in their home language, fostering their feeling of belongingness in the science center.

4. Discussion

Results from educator survey data indicated that SISTEM educators grew in their sense of self-efficacy in science teaching—and specifically in science teaching for EMLs. While these results are correlational in nature, based on existing research on effective PL experiences for educators, we theorize that engaging educators with interactive, hands-on learning opportunities in workshops tied to classroom practice [80–82] and providing educators with chances to reflect on their practice that included opportunities for ongoing support through a virtual PL community [8] helped to foster educators' feelings of comfort, thus facilitating high-quality science experiences for EMLs.

To ensure that our instruction was responsive to educators' needs, we employed an ongoing process of formative assessment during the PL sessions. For example, in our first PL session, we engaged educators in two adult immersive explorations of water—one open and one focused—with the goal of building their content knowledge related to the topic. However, we learned from subsequent PLCs that educators were not fully leveraging the *PEEP* resources as they planned Water explorations for their own classrooms. To help them do so for Ramps and Shadows, we changed our approach; in PL Sessions 2 and 3, we invited educators to engage with five or six topical stations drawn directly from *PEEP* rather than in one open and one-focused immersive experience.

Based on observations of educators' science teaching, contrasting SISTEM classrooms with comparison classrooms, and assessing changes from before and after program implementation, results indicate that SISTEM was associated with increased quality in educators' science teaching. Given that our sample of classrooms was quite modest, we were pleasantly surprised to see a significant change in teaching practice related to promoting children's use of scientific inquiry, which was a major emphasis of the PL. The magnitude of this effect—a one-point difference between SISTEM and comparison classrooms on the STERS coding rubric (i.e., a change from "inadequate" to "adequate" support for children's science inquiry)—represents a meaningful difference. Based on indicators for these scores in the STERS codebook [78], this could be described as a shift from talking about science experiences "*as a way of providing information or giving instructions*" to encouraging "*discussions and/or reporting on science experiences*", or a shift from providing children with science experiences that afford "*isolated opportunities for inquiry*" to supporting children to use "*specific scientific inquiry skills, such as exploration, observation, and sharing*". This shift aligns with educators' self-reflections that they had moved from one-time science activities to long-term investigations, and from a didactic approach of imparting science knowledge to a scaffolded approach to supporting children's genuine use of inquiry. These are meaningful changes in teaching practice that have the potential to shape children's ability to use inquiry skills.

Interestingly, comparison teachers showed a slight improvement in their spring scores on a specific STERS item: "*Facilitate direct experiences to promote conceptual learning*". This may have been related to the topic of Shadows. Although teachers were free to choose any science topic for their fall observation, all teachers led an activity related to Shadows in the spring. For this item, teachers were evaluated based on the degree to which they structured "*science experiences that provide a high level of engagement, allowing children to directly experience scientific phenomena*". Asking teachers to explore a physical science topic that is conducive to direct exploration may have naturally increased this aspect of quality in science instruction. It is also possible that for programs that included both SISTEM and comparison classrooms, SISTEM educators may have shared some of what they learned with comparison classrooms over the course of the year.

An important part of supporting children's use of scientific inquiry is asking productive questions. This is a sophisticated skill that involves not only knowing the kinds of questions that can support inquiry, but also knowing when and how to ask such questions, based on a teacher's specific learning goals for the children and on children's cues, responses, and unique language skills. Analysis of classroom observations and educators' self-report survey data indicated that educators improved in their ability to construct and use questions to elicit student thinking and then move it forward. Central to supporting teachers to carry out this work was to have an emphasis in the PL on integrating science inquiry and language development and leveraging children's home language to support their engagement in science. We supported monolingual and bilingual educators in using strategies to foster both children's home language skills and their English language skills in the context of rich explorations of science phenomena. For some participating teachers, especially those who had been trained to conduct instruction in English only, thinking about EMLs' home language as an asset to learning required a paradigm shift. However, as educators moved to an asset-based approach to multilingualism, they were supported to engage with families in a way that allowed for reciprocal sharing and learning.

Caregivers who participated in SISTEM reported increased positive beliefs and attitudes about supporting their children's science learning and interest in STEM. Based on caregivers' reflections, these shifts in thinking may have been supported by shifts in their relationships with their children's teachers; feeling connected to the teacher and the learning happening in the classroom gave caregivers confidence to explore science at home and at the science center. Once families started exploring science together in these contexts, their positive experiences of having fun together as a family were self-reinforcing. Interestingly, families reported a substantial increase in their understanding of the importance of science for their child's future career and their awareness of the types of STEM careers their child could have later in life. This is an important marker, as particular parent behaviors—such as being actively involved in their children's science learning, initiating and sustaining science talk, and making connections between science and their children's daily lives—are associated with sustaining children's engagement in science [13,18,83,84]. Additionally, ISLE experiences have been shown to build parents' confidence and agency in supporting their children's science inquiry [15,85]. This study provides further support for linking formal and informal learning environments in science.

Assessing child outcomes was not within the scope of this study; we suspect, however, that supporting educators and primary caregivers to engage together in reciprocal sharing and learning and to plan rich and connected science experiences for EMLs across contexts may be especially powerful for supporting children's learning, particularly for EMLs [45,46,67,68]. Future research should investigate how this approach can support changes in child outcomes, including interest in STEM, ability to engage in science inquiry, and language skills. Importantly for EMLs, this approach has the potential to build children's oral language skills in both English and their home language, while simultaneously building conceptual learning in science.

While ISLEs have not historically acknowledged the sociocultural aspects of science and science learning, this project showed that a partnership between families, schools, and the community can shift the power dynamics of an institution from one that typically reflects broad historical and systemic inequities [66] to one that promotes and values alternative ways of knowing and learning science, and highlights the critical role of language in science sensemaking [86,87]. Additionally, a unique component of this project was to leverage the science center's connections in broadening the local community's awareness of STEM by engaging diverse employees from local STEM industries to serve as powerful STEM role models—specifically engaging role models who reflected children's and families' ethnicities and languages. Introducing Spanish-speaking STEM professionals as role models may have helped to broaden families' understanding of what STEM careers look like; in addition, it supported families in seeing their children as capable of doing, learning, and pursuing STEM opportunities.

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References

1. McClure, E.R.; Guernsey, L.; Clements, D.H.; Bales, S.N.; Nichols, J.; Kendall-Taylor, N.; Levine, M.H. *STEM Starts Early: Grounding Science, Technology, Engineering, and Math Education in Early Childhood*; The Joan Ganz Cooney Center at Sesame Workshop: New York, NY, USA, 2017.
2. Saçkes, M.; Trundle, K.C.; Bell, R.L.; O'Connell, A.A. The influence of early science experience in kindergarten on children's immediate and later science achievement: Evidence from the early childhood longitudinal study. *J. Res. Sci. Teach.* **2011**, *48*, 217–235. [CrossRef]

3. Bustamante, A.S.; Greenfield, D.B.; Nayfeld, I. Early childhood science and engineering: Engaging platforms for fostering domain-general learning skills. *Educ. Sci.* **2018**, *8*, 144. [CrossRef]
4. Whitebread, D.; Neale, D.; Jensen, H.; Liu, C.; Solis, S.L.; Hopkins, E.; Hirsh-Pasek, K.; Zosh, J.M. *The Role of Play in Children's Development: A Review of the Evidence*; Research Summary; The Lego Foundation: Billund, Denmark, 2017. [CrossRef]
5. Brenneman, K.; Stevenson-Boyd, J.; Frede, E. Math and Science in Preschool: Policies and Practice. Preschool Policy Brief. National Institute for Early Education Research. Available online: https://nieer.org/sites/default/files/2023-08/20.pdf (accessed on 1 July 2024).
6. Lee, O. Science education with English language learners: Synthesis and research agenda. *Rev. Educ. Res.* **2005**, *75*, 491–530. [CrossRef]
7. Greenfield, D.; Jirout, J.; Dominguez, X.; Greenberg, A.; Maier, M.; Fuccillo, J. Science in the preschool classroom: A programmatic research agenda to improve science readiness. *Early Educ. Dev.* **2009**, *20*, 238–264. [CrossRef]
8. Lange, A.A.; Nayfeld, I.; Mano, H.; Jung, K. Experimental effects of a preschool STEM professional learning model on educators' attitudes, beliefs, confidence, and knowledge. *J. Early Child. Teach. Educ.* **2021**, *43*, 509–539. [CrossRef]
9. Allen, L.; Kelly, B.B. (Eds.) *Transforming the Workforce for Children Birth through Age 8: A Unifying Foundation*; National Academies Press: Washington, DC, USA, 2015.
10. Hadani, H.S.; Rood, E. *The Roots of STEM Success: Changing Early Learning Experiences to Build Lifelong Thinking Skills*; Center for Childhood Creativity: Sausalito, CA, USA, 2018; Available online: https://fpg.unc.edu/sites/fpg.unc.edu/files/resources/presentations-and-webinars/CCC_The_Roots_of_STEM_Early_Learning_0.pdf (accessed on 1 July 2024).
11. Alexander, J.M.; Johnson, K.E.; Kelley, K. Longitudinal analysis of the relations between opportunities to learn about science and the development of interests related to science. *Sci. Educ.* **2012**, *96*, 763–786. [CrossRef]
12. Bodnar, K.; Hofkens, T.L.; Wang, M.-T.; Schunn, C.D. Science identity predicts science career aspiration across gender and race, but especially for White boys. *Int. J. Gend. Sci. Technol.* **2020**, *12*, 32–45. Available online: https://genderandset.open.ac.uk/index.php/genderandset/article/view/675 (accessed on 1 July 2024).
13. Pattison, S.A. Exploring the Foundations of Science Interest Development in Early Childhood. Ph.D. Dissertation, Oregon State University, Corvallis, OR, USA, 2015. Available online: http://hdl.handle.net/1957/54783 (accessed on 1 July 2024).
14. Pattison, S.; Ramos-Montañez, S.; Santiago, A.; Svarovsky, G.; Douglass, A.; Núñez, V.; Allen, J.; Wagner, C. Interest catalysts: The unique ways families connect with program experiences to support long-term STEM interest pathways in early childhood [Conference presentation]. In Proceedings of the NARST 2022 Annual International Conference, Vancouver, BC, Canada, 27–30 March 2022; Available online: https://www.terc.edu/publications/interest-catalysts-the-unique-ways-families-connect-with-program-experiences-to-support-long-term-stem-interest-pathways-in-early-childhood/ (accessed on 1 July 2024).
15. Silander, M.; Grindal, T.; Hupert, N.; Garcia, E.; Anderson, K.; Vahey, P.; Pasnik, S. *What Caregivers Talk about When They Talk about Learning: A National Survey about Young Children and Science*; Education Development Center, Inc., & SRI International: Waltham, MA, USA, 2018; Available online: https://www.edc.org/sites/default/files/uploads/EDC_SRI_What_Parents_Talk_About.pdf (accessed on 1 July 2024).
16. Turkle, S. *Falling for Science: Objects in Mind*; MIT Press: Cambridge, MA, USA, 2008.
17. Weiss, H.B.; Bouffard, S.M.; Bridglall, B.L.; Gordon, E.W. Reframing Family Involvement in Education: Supporting Families to Support Educational Equity. Equity Matters. Research Review No. 5. ERIC. 2009. Available online: https://files.eric.ed.gov/fulltext/ED523994.pdf (accessed on 1 July 2024).
18. Callanan, M.A.; Castañeda, C.L.; Luce, M.R.; Martin, J.L. Family science talk in museums: Predicting children's engagement from variations in talk and activity. *Child Dev.* **2017**, *88*, 1492–1504. [CrossRef]
19. Haden, C.A. Talking about science in museums. *Child Dev. Perspect.* **2010**, *4*, 62–67. [CrossRef]
20. Gerde, H.; Pierce, S.; Lee, K.; Egeren, L. Early Childhood Educators' Self-Efficacy in Science, Math, and Literacy Instruction and Science Practice in the Classroom. *Early Educ. Dev.* **2017**, *29*, 70–90. [CrossRef]
21. Gelman, R.; Brenneman, K.; Macdonald, G.; Roman, M. *Preschool Pathways to Science: Ways of Doing, Thinking, Communicating and Knowing about Science*; Brookes Publishing Company: Baltimore, MD, USA, 2010.
22. Kanter, D.E.; Konstantopoulos, S. The impact of a project-based science curriculum on minority student achievement, attitudes, and careers: The effects of teacher content and pedagogical content knowledge and inquiry-based practices. *Sci. Educ.* **2010**, *94*, 855–887. [CrossRef]
23. Tabors, P. *One Child, Two Languages: A Guide for Early Childhood Educators of Children Learning English as a Second Language*, 2nd ed.; Brookes Publishing Company: Baltimore, MD, USA, 2008.
24. Calabrese Barton, A.C.; Drake, C.; Perez, J.G.; Louis, K.S.; George, M. Ecologies of parental engagement in urban education. *Educ. Res.* **2004**, *33*, 3–12. [CrossRef]
25. Reinhart, M.; Bloomquist, D.; Strickler-Eppard, L.; Czerniak, C.M.; Gilbert, A.; Kaderavek, J.; Molitor, S.C. Taking science home: Connecting schools and families through science activity packs for young children. *Sch. Sci. Math.* **2016**, *116*, 3–16. [CrossRef]
26. Sonnenschein, S.; Stites, M.; Dowling, R. Learning at home: What preschool children's parents do and what they want to learn from their children's teachers. *J. Early Child. Res.* **2021**, *19*, 309–322. [CrossRef]
27. Bian, L.; Leslie, S.-J.; Cimpian, A. Gender stereotypes about intellectual ability emerge early and influence children's interests. *Science* **2017**, *355*, 389–391. Available online: http://science.sciencemag.org/content/355/6323/389.full (accessed on 1 July 2024). [CrossRef] [PubMed]

28. Newitz, A. Why Are Scientists Always the Bad Guys in Movies? (6 October 2014). Gizmodo. Available online: http://io9.com/why-are-scientists-always-the-bad-guys-in-movies-1643054457 (accessed on 1 July 2024).
29. Zarate, M. *Understanding Latino Parental Involvement in Education: Perceptions, Expectations, and Recommendations [Policy Paper]*; The Tomas Rivera Policy Institute: Los Angeles, CA, USA, 2007. Available online: https://files.eric.ed.gov/fulltext/ED502065.pdf (accessed on 1 July 2024).
30. Cooper, C.E.; Crosnoe, R.; Suizzo, M.; Pituch, K.A. Poverty, race, and parental involvement during the transition to elementary school. *J. Fam. Issues* **2010**, *31*, 859–883. [CrossRef]
31. Espinosa, L.M. Assessment of young English language learners. In *Young English Language Learners: Current Research and Emerging Directions for Practice and Policy*; García, E.E., Frede, E.C., Eds.; Teachers College Press: New York, NY, USA, 2010; pp. 119–142.
32. Lahaie, C. School readiness of children of immigrants: Does parental involvement play a role? *Soc. Sci. Q.* **2008**, *89*, 684–705. [CrossRef]
33. Figueras-Daniel, A. Key Influences on the Quality and Outcomes of Preschool Education for Dual Language Learners: Professional Learning and Bilingual Staffing Patterns. (Publication No. 3544643). Doctoral Dissertation, Rutgers University, New Brunswick, NJ, USA, 2016. Available online: https://rucore.libraries.rutgers.edu/rutgers-lib/51260/ (accessed on 1 July 2024).
34. Gándara, P.; Maxwell-Jolly, J.; Driscoll, A. *Listening to Teachers of English Language Learners: A Survey of California Teachers' Challenges, Experiences, and Professional Development Needs*; The Center for the Future of Teaching and Learning: San Francisco, CA, USA, 2005.
35. Anderhag, P.; Wickman, P.; Bergqvist, K.; Jakobson, B.; Hamza, K.; Saljo, R. Why do secondary school students lose their interest in science? Or does it never emerge? A possible and overlooked explanation. *Sci. Educ.* **2016**, *100*, 783–951. Available online: https://onlinelibrary.wiley.com/toc/1098237x/100/5 (accessed on 1 July 2024). [CrossRef]
36. Legare, C.H.; Lombrozo, T. Selective effects of explanation on learning during early childhood. *J. Exp. Child Psychol.* **2014**, *126*, 198–212. [CrossRef]
37. Walker, C.M.; Lombrozo, T.; Legare, C.H.; Gopnik, A. Explaining prompts children to privilege inductively rich properties. *Cognition* **2014**, *133*, 343–357. [CrossRef]
38. Stoddart, T.; Pinal, A.; Latzke, M.; Canaday, D. Integrating inquiry science and language development for English language learners. *J. Res. Sci Teach.* **2002**, *39*, 684–687. Available online: http://homepages.gac.edu/~mkoomen/restored/Science%20Articles/inquiryandell.pdf (accessed on 1 July 2024). [CrossRef]
39. Méndez, L.I.; Crais, E.R.; Kainz, K. The impact of individual differences on a bilingual vocabulary approach for Latino preschoolers. *J. Speech Lang. Hear. Res.* **2018**, *61*, 897–909. [CrossRef] [PubMed]
40. Wright, T.; Gotwals, A. Supporting disciplinary talk from the start of school: Teaching students to think. *Read. Teach.* **2017**, *71*, 189–197. [CrossRef]
41. Baroody, A.J.; Bajwa, N.P.; Eiland, M. Why can't Johnny remember the basic facts? *Dev. Disabil. Res. Rev.* **2009**, *15*, 69–79. [CrossRef] [PubMed]
42. Sarama, J.; Lange, A.A.; Clements, D.H.; Wolfe, C.B. The impacts of an early mathematics curriculum on oral language and literacy. *Early Child. Res. Q.* **2012**, *27*, 489–502. [CrossRef]
43. Archer, L.; DeWitt, J.; Osborne, J.; Dillon, J.; Willis, B.; Wong, B. Science aspirations, capital, and family habitus: How families shape children's engagement and identification with science. *Am. Educ. Res. J.* **2012**, *49*, 881–908. [CrossRef]
44. Mapp, K.; Kuttner, P. Partners in Education: A Dual Capacity-Building Framework for Family–School Partnerships. SEDL. 2013. Available online: https://www2.ed.gov/documents/family-community/partners-education.pdf (accessed on 1 July 2024).
45. Hoisington, C.; Young, J.M.; Anastasopoulos, L.; Washburn, S. Building a classroom community that supports English learners in preschool. *NHSA Dialog* **2015**, *18*, 1–30.
46. Hoisington, C.; Young, J.; Anastasopoulos, L.; Washburn, S. Supporting English learners in preschool: Strategies for teachers. *NHSA Dialog* **2015**, *18*, 85–91.
47. Espinosa, L.M.; Hayslip, W. *Promoting Kindergarten Readiness for Dual Language Learners: Evidence-Based Language Models and Transition Strategies*; REL Northeast & Islands, REL West, and the Cross-REL English Learners Working Group, 2019.
48. Magruder, E.S.; Hayslip, W.W.; Espinosa, L.M.; Matera, C. Many languages, one teacher: Supporting language and literacy development for preschool dual language learners. *Young Child.* **2013**, *68*, 8–15.
49. Henderson, A.; Mapp, K. A New Wave of Evidence: The Impact of School, Family, and Community Connections on Student Achievement. Annual Synthesis 2002. Southwest Educational Development Laboratory. 2002. Available online: https://files.eric.ed.gov/fulltext/ED474521.pdf (accessed on 1 July 2024).
50. Institute of Medicine & National Research Council. *From Neurons to Neighborhoods: An Update: Workshop Summary*; National Academies Press: Washington, DC, USA, 2012.
51. Bialystok, E. Cognitive effects of bilingualism across the lifespan. In *BUCLD 32: Proceedings of the 32nd Annual Boston University Conference on Language Development*; Chan, H., Jacob, H., Kapia, E., Eds.; Cascadilla Press: Somerville, MA, USA, 2008; pp. 1–15.
52. Genesee, F. Dual language development in preschool children. In *Young English Language Learners: Current Research and Emerging Directions for Practice and Policy*; García, E.E., Frede, E.C., Eds.; Teachers College Press: New York, NY, USA, 2010; pp. 59–79.
53. Dabney, K.; Tai, R.; Scott, M. Informal science: Family education, experiences, and initial interest in science. *Int. J. Sci. Educ. Part B Commun. Public Engagem.* **2016**, *6*, 263–282. [CrossRef]

54. Weiss, H.; Little, P.; Bouffard, S.; Deschenes, S.; Malone, H. The Federal Role in Out of School Learning: After-School, Summer Learning, and Family Involvement as Critical Learning Supports. 2009. Available online: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjGr-3PvdHlAhWh1FkKHXtCD_AQFjAAegQIARAC&url=https://pdfs.semanticscholar.org/5494/1d35206f00990ec759da20d92d8f52fa29c2.pdf&usg=AOvVaw0bmd9ULoN7vv8nfPho0Z1B (accessed on 1 July 2024).
55. Egalite, A.J.; Kisida, B. The Effects of Teacher Match on Students' Academic Perceptions and Attitudes. *Educ. Eval. Policy Anal.* **2018**, *40*, 59–81. [CrossRef]
56. Bell, P.; Lewenstein, B.; Shouse, A.W.; Feder, M.A. (Eds.) *Learning Science in Informal Environments: People, Places, and Pursuits*; National Academies Press: Washington, DC, USA, 2009.
57. Blank, M.J.; Jacobson, R.; Melaville, A.I. *Achieving Results through Community School Partnerships: How District and Community Leaders Are Building Effective, Sustainable Relationships*; Center for American Progress: Washington, DC, USA, 2012.
58. Dang, M.; Nylund-Gibson, K. Connecting math attitudes with STEM career attainment: A latent class analysis approach. *Teach. Coll. Rec.* **2017**, *119*, 1–38. [CrossRef]
59. National Research Council. *Learning Science in Informal Environments: People, Places, and Pursuits*; National Academies Press: Washington, DC, USA, 2009. [CrossRef]
60. Dou, R.; Hazari, Z.; Dabney, K.; Sonnert, G.; Sadler, P. Early informal STEM experiences and STEM Identity: The Importance of Talking Science. *Sci. Educ.* **2019**, *103*, 623–637. [CrossRef]
61. McCreedy, D.; Dierking, L.D. *Cascading Influences: Long-Term Impacts of Informal STEM Experiences for Girls*; The Franklin Institute Science Museum: Philadelphia, PA, USA, 2013; Available online: https://www.fi.edu/sites/default/files/cascading-influences.pdf (accessed on 1 July 2024).
62. Olle, C.; Fouad, N. Parental Support, Critical Consciousness, and Agency in Career Decision Making for Urban Students. *J. Career Assess.* **2015**, *23*, 533–544. [CrossRef]
63. Rigney, J.C.; Callanan, M.A. Patterns in parent–child conversations about animals at a marine science center. *Cogn. Dev.* **2011**, *26*, 155–171. [CrossRef]
64. Dawson, E. Equity in informal science education: Developing an access and equity framework for science museums and science centres. *Stud. Sci. Educ.* **2014**, *50*, 209–247. [CrossRef]
65. Santiago, A. Focusing on cultural competency in STEM education. *Informal Sci.* **2017**, *1*, 1–16. Available online: https://www.informalscience.org/sites/default/files/Focusing%20on%20Cultural%20Competence%20in%20STEM%20Education.pdf (accessed on 1 July 2024).
66. Ishimaru, A.M.; Torres, K.E.; Salvador, J.E.; Lott, J.; Williams, D.M.C.; Tran, C. Reinforcing Deficit, Journeying Toward Equity: Cultural Brokering in Family Engagement Initiatives. *Am. Educ. Res. J.* **2016**, *53*, 850–882. Available online: http://www.jstor.org/stable/24751617 (accessed on 1 July 2024). [CrossRef]
67. Bronfenbrenner, U. Recent advances in research on the ecology of human development. In *Development as Action in Context: Problem Behavior and Normal Youth Development*; Springer: Berlin/Heidelberg, Germany, 1986; pp. 287–309.
68. Bronfenbrenner, U. Toward an experimental ecology of human development. *Am. Psychol.* **1977**, *32*, 513–531. [CrossRef]
69. Lave, J.; Wenger, E. *Situated Learning: Legitimate Peripheral Participation*; Cambridge University Press: New York, NY, USA, 1991.
70. Rogoff, B. *The Cultural Nature of Human Development*; Oxford University Press: Oxford, UK, 2003.
71. Verhoeven, M.; Poorthuis, A.M.G.; Volman, M. The Role of School in Adolescents' Identity Development. A Literature Review. *Educ. Psychol. Rev.* **2019**, *31*, 35–63. [CrossRef]
72. Kolmar, C. The 10 poorest cities in Connecticut for 2024. RoadSnacks. Available online: https://www.roadsnacks.net/poorest-places-in-connecticut/ (accessed on 2 January 2024).
73. Department of Housing and Urban Development. North Hartford Promise Zone [Factsheet]. 2015. Available online: https://www.hudexchange.info/sites/onecpd/assets/File/Promise-Zone-Designee-North-Hartford.pdf (accessed on 1 July 2024).
74. Gonzalez, N.; Moll, L.C.; Amanti, C. (Eds.) *Funds of Knowledge: Theorizing Practices in Households, Communities, and Classrooms*, 1st ed.; Lawrence Erlbaum Associates Publishers: Mahwah, NJ, USA, 2005. [CrossRef]
75. Moll, L.C.; Amanti, C.; Neff, D.; Gonzalez, N. Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory Into Pract.* **1992**, *31*, 132–141. [CrossRef]
76. Yosso, T.J. Whose culture has capital? A critical race theory discussion of community cultural wealth. *Race Ethn. Educ.* **2005**, *8*, 69–91. [CrossRef]
77. Connecticut Office of Early Childhood. Connecticut Early Learning and Development Standards (CT ELDS). Available online: https://www.ctoec.org/supporting-child-development/ct-elds/#CTELDSDocs (accessed on 1 July 2024).
78. Chalufour, I.; Worth, K.; Clark-Chiarelli, N. *Science Teaching Environment Rating Scale (STERS)*; Education Development Center: Newton, MA, USA, 2009.
79. Gropen, J.; Kook, J.F.; Hoisington, C.; Clark-Chiarelli, N. Foundations of science literacy: Efficacy of a preschool professional development program in science on classroom instruction, teachers' pedagogical content knowledge, and children's observations and predictions. *Early Educ. Dev.* **2017**, *28*, 607–631. [CrossRef]
80. Zaslow, M. General features of effective professional development. In *Preparing Early Childhood Educators to Teach Math*; Ginsburg, H.P., Hyson, M., Woods, T.A., Eds.; Paul H. Brookes Publishing: Towson, MD, USA, 2014; pp. 97–115. Available online: http://archive.brookespublishing.com/documents/ginsburg-early-math-professional-development.pdf (accessed on 1 July 2024).

81. Zaslow, M.; Martinez-Beck, I. *Critical Issues in Early Childhood Professional Development*; Paul H. Brookes Publishing: Towson, MD, USA, 2005.
82. Zaslow, M.; Tout, K.; Halle, T.; Starr, R. Professional development for early childhood educators: Reviewing and revising conceptualizations. In *Handbook of Early Literacy Research*; Neuman, S.B., Dickinson, D.K., Eds.; The Guilford Press: New York, NY, USA, 2011; pp. 425–434.
83. Fender, J.G.; Crowley, K. How parent explanation changes what children learn from everyday scientific thinking. *J. Appl. Dev. Psychol.* **2007**, *28*, 189–210. [CrossRef]
84. Leibham, M.B.; Alexander, J.M.; Johnson, K.E. Science interests in preschool boys and girls: Relations to later self-concept and science achievement. *Sci. Educ.* **2013**, *97*, 574–593. [CrossRef]
85. Garibay, C. Latinos, leisure values, and decisions: Implications for informal science learning and engagement. *Informal Learn. Rev.* **2009**, *94*, 10–13.
86. Ash, D.; Rahm, J.; Melber, L.M. *Putting Theory into Practice: Tools for Research in Informal Settings*; Sense Publishers: Rotterdam, The Netherlands, 2012.
87. Bevan, B.; Calabrese Barton, A.; Garibay, C. Broadening Perspectives on Broadening Participation in STEM: Critical Perspectives on the Role of Science Engagement. Center for Advancement of Informal Science Education. 2018. Available online: http://informalscience.org/sites/default/files/BP-Report.pdf (accessed on 1 July 2024).

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Article

Teaching Topic Preferences in the Nature–Human–Society Subject: How Trainee Teachers Justify Their Likes and Dislikes

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Abstract: This study focuses on the description and explanation of trainee teachers' attitudes in specific educational situations. More precisely, it demonstrates the reasons why they prefer to teach certain Nature–Human–Society topics over others and, conversely, why they do not like teaching some of those topics—particularly science topics relating to physics and technology. The description of these arguments is relevant because trainee teachers' attitudes can have an impact on later teacher behavior, especially in a multidisciplinary subject such as Nature—Human–Society, where different topics can be given different amounts of time and importance in class. The results of this study are based on a survey of a student cohort in teacher training in Switzerland. The arguments for liking or disliking a total of twelve teaching topics in the subject Nature–Human–Society were elicited through open-ended questions and theoretically assigned to three attitude dimensions—cognitive beliefs, affective access, and perceived control—following qualitative content analysis. Differences in the reasons for liking and disliking certain teaching topics are shown, as well as the general finding that liking teaching topics is primarily based on cognitive beliefs, while disliking teaching topics is primarily attributed to lacking perceived control or lacking affective access to trainee teachers.

Keywords: attitudes; beliefs; interests; sciences; social studies; kindergarten; primary education; teachers; teaching; early childhood; science education

1. Introduction

Curricula form the framework for learning in schools. They define the goals, competence expectations, and standards that children should achieve in a certain educational institution. However, as important as these written guidelines are, they only develop their full effect through the people who implement them: the teachers. As the direct interface between theory and practice, they play a key role in the design of lessons. They interpret the curriculum guidelines, select suitable teaching methods, and adapt teaching materials to the individual needs of their learners. Thus, they can contribute significantly to the quality of teaching by creating effective learning opportunities and optimal conditions for child development [1–4]. Conversely, it is also important to recognize that their choices and actions can also have a detrimental impact on pupils' outcomes. The example of science education clearly demonstrates that, despite the increased demand for early science education in recent years, which is also reflected in kindergarten and primary school curricula, the reality of classroom instruction is sometimes different. Research has consistently shown that the teacher's attitude toward science significantly influences their teaching practices and their willingness to teach science. This means that the extent to which certain science content and methods are thought of and integrated into the subject lessons is highly dependent on the individual teachers [2,4–6]. Given the research indicating that a significant number of elementary and primary teachers possess negative attitudes towards science education, it is evident that this is a widespread rather than an isolated issue. Teacher training programs must therefore effectively address this issue by cultivating positive attitudes in trainee teachers and thereby empowering science education in kindergarten and primary schools [2,4,6,7].

While the curricula for primary education of some countries primarily focus on integrating the natural sciences (biology, chemistry, and physics) into one subject, others take a broader approach, incorporating elements of social studies, geography, and even history into one subject—as in Switzerland, where science is taught in the subject Nature–Human–Society [8]. Nature–Human–Society is a unique and relatively new subject in the Swiss educational landscape. The subject "Natur–Mensch–Gesellschaft", as it was originally named and abbreviated as NMG, was established throughout Switzerland in 2016 with the introduction of a common curriculum. Formerly, there were similar subject areas in several cantons, but they often had different names, focuses, and disciplinary compositions. The educational area of Nature–Human–Society was created as a multidisciplinary subject from Swiss kindergarten to primary school, extending to the sixth grade. It comprises four content areas: (I) Nature and Technology, (II) Economics, Work, Housekeeping, (III) Geography, History, Societies, and (IV) Ethics, Religions, Community. All four content areas are concerned with the world that surrounds people. The term world refers here to the natural, economic, cultural, and social environment. According to the Swiss curriculum, as early as kindergarten and primary school, children should engage with this world by observing, investigating, classifying, and understanding various phenomena so that they can ultimately participate actively in this world and act responsibly toward their living environment in the future [1,9–11].

The Swiss primary school children who were interviewed about Nature–Human–Society lessons generally saw it as an interesting and attractive subject. Many pupils also named it as one of their favorite subjects. Furthermore, most of the pupils surveyed attached great importance to this subject, believing that the content of this subject is relevant to their current lives and will help them later in life. However, some pupils also stated that their attitude towards NMG lessons depends on their interest in the topics covered in class. In an exploratory longitudinal study, which surveyed the same children at the beginning of the first, third, fifth, and seventh grades, it was found that the general elevated interest in various NMG topics tends to decrease slowly from the lower grades to the higher grades. However, over this period of primary school, some subject areas continuously emerge as areas of great interest for many of the children, namely topics about animals, astronomy, phenomena of inanimate nature, and technology [12] (see Figure 1).

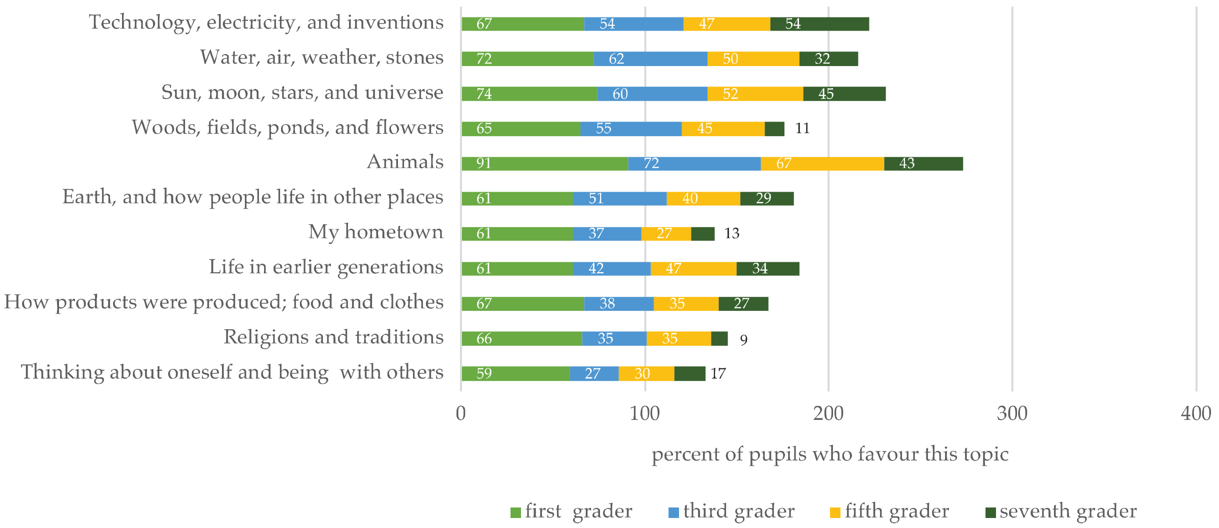

Figure 1. Percentages of pupils from four different year classes (therefore, the axle extends to 400 percent) who indicated on a 4-level Likert-scale (with 4 meaning "very much" and 1 meaning "not at all") to like the various teaching topics of the Nature–Human–Society subject "very much" (n = 61 first-graders, 65 third-graders, 61 fifth-graders, and 58 seventh-graders) [12].

When asked about the reasons pupils are particularly interested in certain Nature–Human–Society topics, interest in fascinating, exciting, adventurous, and mysterious themes was frequently cited. The curiosity to know what has already been discovered about phenomena seemed to characterize their choices [12]. These results can be well integrated into Krapp's theory [13,14] of interest, which offers a comprehensive framework for comprehending the intricate connections between an individual and an object of interest. According to this person–object theory of interest, there are three characterized aspects that influence the involvement and engagement of learning things: (I) when the subject or a possible action derived from it has a high subjective value for the pupil (value aspect), (II) when dealing with the subject matter or a possible action derived from it is associated with positive feelings for the learner (emotional aspect), and (III) when the learner wants to ascertain and learn more about the matter (cognitive aspect).

In conjunction with the intrinsic motivation of pupils, driven by internal factors such as curiosity, interest, and personal satisfaction [15,16], the role of teachers in inspiring and nurturing pupils' motivation is crucial in kindergarten and primary school. A teacher's enthusiasm and interest in the subject matter can promote the children's situational interest in the various subject matters since these teacher variables have a decisive influence on creating a motivating learning arrangement [17–21]. However, if we look at trainee teachers surveys [22–26], it becomes clear that their attitudes towards Nature–Human–Society topics are somewhat different. In contrast to primary school pupils, trainee teachers are often not very fond of the physical–technical area and, conversely, usually have a greater interest in social–ethical topics than the pupils in the study described above.

A qualitative exploratory study [27] with Swiss teacher candidates already revealed why specific teaching topics within Natural–Human–Society were particularly engaging. According to these findings, identity formation for trainee teachers is an indispensable topic in Nature–Human–Society lessons. The obvious importance of identity building can probably be attributed to the life phase of later adolescence, the phase with which the surveyed trainee teachers were concerned and the questions they themselves presumably dealt with most. In this context, trainee teachers often stated that children's learning should take place concentrically, starting from the individual in the center and then moving towards the outside world. It was also noticeable that trainee teachers sometimes had an unusual concept of the living environment. The forest, for example, was seen as being related to life, while electricity was not. Moreover, the human–environment relationship was mentioned as a central topic among the trainee teachers, with teaching perspectives about environmental protection being considered particularly important [27]. The value placed on environmental protection and sustainability can be seen as an expression of a global identity that is currently on the rise and is held in respect by many adolescents and adults, and thus also by several trainee teachers [28].

A variety of quantitative studies have also delved into the reasons behind the popularity and unpopularity of subjects among future teachers of primary education [22–26]. Now we will briefly summarize the current state of research specifically focusing on studies on trainee teachers' attitudes within the Nature–Human–Society field (for more details, please see [23–26]). Given the established link between knowledge, ability self-concept, and interest, these variables were the focus of research on trainee teachers' attitudes regarding the teaching of Nature–Human–Society topics [23,25]. In addition, personality-specific characteristics of trainee teachers, specifically the Big Five personality traits, as well as Hollands' six types of vocational personalities, were subject to more in-depth analysis [24,26]. Research findings demonstrated that trainee teachers have a generally pronounced social and artistic interest, as well as a higher Big Five extraversion score, which was linked to teaching topic preferences for people-related topics and, conversely, implicated that thing-oriented topics are rather unpopular with trainee teachers [24,26]. Higher confidence in teaching thing-related topics such as physics and technology topics among trainee teachers correlated closely with higher realistic and investigative interests, lower Big Five neuroticism scores, as well as a better general knowledge of science and technology [25].

In contrast to natural sciences topics, it turned out that in humanities and social sciences topics, there was no correlation between general knowledge of humanities and social sciences and the perceived capability of trainee teachers towards those teaching topics. This indicated that the popularity of teaching such topics does not depend on one's own knowledge and on the related ability self-concepts of these subject areas but more on the affective-evaluative part of attitude and thus on their affinity for these topics [23].

Generally, it is widely recognized that the attitude concept is a multidimensional construct, being influenced by three main elements: a cognitive component (thoughts and beliefs), an affective component (feelings and emotions), and a behavioral component (tendencies to act) [29]. According to a new theoretical framework for explicitly describing primary teachers' attitudes toward teaching science, which was developed after reviewing and theoretically evaluating attitude concepts in previous studies, the following three crucial components are decisive for the formation of attitudes in science teaching: (I) cognitive beliefs (perceived relevance, perceived difficulty, and gender beliefs), (II) affective states (enjoyment and anxiety), and (III) perceived control (self-efficacy and perceived dependency on context factors) [30]. However, it is unclear whether this theoretical framework can also be applied to other teaching contexts or subject matters.

This research aims to explore trainee teachers' own arguments for favoring or disliking certain teaching topics in Nature–Human–Society, thus determining the specific aspects that characterize attitudes regarding different subject areas of Nature–Human–Society before teacher training takes place in order to exert targeted training if necessary. It is intended to supplement existing findings from quantitative studies, providing a deeper understanding of the reasons for the popularity and unpopularity of the different Nature–Human–Society topics. Until now, no previous study has used open-ended questions to ask trainee teacher students to give the reasons for both popular and unpopular topics in the Nature–Human–Society subject. Such an approach was chosen at this time to comprehensively record the perspectives of the individual participants, letting them express their assertions for themselves [31]. Thus, this study aims to uncover nuances in a way that is difficult to chronicle from solely quantitative studies.

Consequently, the following research question guided this research:

- How do trainee teachers justify their likes and dislikes for Nature–Human–Society teaching topics?
- Are there arguments for liking and, respectively, disliking teaching topics that are more pronounced in some teaching topics of Nature–Human–Society than others, or can a similar pattern of argumentation be found in all Nature–Human–Society topics?

To achieve the research aims, a study with newcomer trainee teachers for kindergartens and primary schools at a university of teacher education in Switzerland was conducted. Initially, for descriptive statistics, an explanation was given on how the sample's affection, experience, and perceived capability regarding various teaching domains of the subject Nature–Human–Society were composed (see Section 3.1), and which teaching topics in Nature–Human–Society are favored and disfavored by the trainee teachers (see Section 3.2). Subsequently, the analysis of reasons for or against teaching certain topics of Nature–Human–Society was shown from the perspective of the surveyed trainee teachers (see Sections 3.3 and 3.4). Finally, the identified argumentation patterns were compared across all Nature–Human–Society topics (see Sections 3.3, 3.4 and 4).

Thus, this study is designed to deepen our comprehension of pre-service teachers' attitudes towards various subject areas of social and natural sciences. By pinpointing the root causes of positive and negative attitudes, we aim to illuminate pathways for enhancing these attitudes within teacher education programs. In the literature [6], there is widespread agreement that attitude-focused approaches in trainee teacher courses may provide fertile ground for evolving or stabilizing teachers' attitudes. Cultivating self-awareness of pre-service teachers' existing attitudes and fostering reflection during their training is a crucial step in this direction.

2. Materials and Methods

2.1. Sample

The sample included all first-year students in the primary education program at the University of Teacher Education Bern (Switzerland) who voluntarily agreed to participate in this study. The aim was to have as complete a cohort as possible, although a less-than-complete response rate was expected. Of the group that consisted of 309 students (83% female and 17% male), 220 students participated (84.1% female and 15.9% male) in the entire survey, representing a response rate of 71.2% and reflecting the gender disbalance fairly since the predominance of female participants is a general characteristic of study cohorts for primary education [32].

The average age of the participants was 23.26 years (SD = 6.3; Min = 18; Max = 50), with the age of 20 being the most frequently occurring score (mode) and the age of 21 as the median. The participating students came to the teacher training program from different educational or professional backgrounds, whereby 59.6% of the participants had a high school degree. The chosen focus of study within teacher training also differed among the participants. Overall, 44.1% of the participants were enrolled in the study focus "cycle 1: teaching kindergarten to grade 2" and 55.9% in the study focus "cycle 2: teaching grades 3 to 6".

2.2. Data Collection and Instruments

For this cross-sectional study, the first-year students of the primary education program were invited to take part in an online survey during the first week of the semester as part of the Nature–Human–Society course. Participation in the anonymous survey was voluntary and lasted about 20 min. The following sections describe the content of the survey.

2.2.1. Q-Sort: Favorite Content to Teach Within the Subject of Nature–Human–Society

At the beginning of the survey, students were asked to choose three topics they would like to teach most from a list of twelve teaching topics of the Nature–Human–Society subject. Then, the students were asked to indicate which three topics from this list they liked least. The topics on the list were as follows: (1) Thinking about oneself, (2) Being with others, (3) Religions and traditions, (4) How products were produced, (5) Life in earlier generations, (6) My hometown, (7) Earth, and how people live in other places, (8) Animals, woods, fields, ponds, and flowers, (9) Sun, moon, stars, and universe, (10) Water, air, weather, and stones, (11) Technology, electricity, and inventions, and (12) Substances and their properties [33].

2.2.2. Open Questions to Justify Topic Preferences or Aversions

After the ranking of popularity/unpopularity was completed by the students, they were asked to state why they liked or disliked teaching these topics. Students could give up to three reasons per topic, formulating their own answers and having to give a justification for a total of six topics (the selected three preferred teaching topics and the selected three unpreferred teaching topics).

2.2.3. Nature–Human–Society Questionnaire (NMG Questionnaire)

To obtain general information on students' assessments of the different Nature–Human–Society content areas, the NMG Questionnaire was used [25]. It is a standardized self-report instrument for Swiss kindergarten and primary school trainee teachers and in-service teachers that asks them to rate the same nine items for each of the following seven Nature–Human–Society content domains: social/ethical, cultural/religious, historical/political, geographical, economic, physical/technical, and biological. Thus, in total, there were 63 items that the students had to rate on a 5-point Likert scale, with the number 1 meaning "strongly disagree" and the number 5 "agree strongly".

For the evaluation, the items, three each, were combined into three scales, which are as follows: Experience, Affection, and Perceived Capability. Thus, these trainee teacher characteristics could be specified for each individual content area of the Nature–Human–Society subject. The scale Experience referred to positive memories and familiar experiences acquired in formal and informal learning settings, the scale Attitude to positive feelings and affinity to a specific content area, and the scale Perceived Capability to self-efficacy beliefs in the field of disciplinary knowledge and the ability to accumulate and impart knowledge. In the questionnaire evaluation, the Cronbach's alphas of the three subscales (Experience, Affection, and Perceived Capability) of all Nature–Human–Society content areas ranged between 0.68 and 0.88 [34].

2.3. Data Analyses

In an SPSS data file, the raw data of the online questionnaire were inserted and initially screened for error outliers or random tick marks to determine the possible questionnaires to be evaluated. Then, general descriptive analyses were performed on the demographic variables to obtain information about the sample composition.

For each Nature–Human–Society domain, the related single items of the NMG Questionnaire were converted into three scales (Experience, Affection, and Perceived Capability) and the Cronbach's alphas were calculated [35]. Furthermore, detailed descriptive statistics [36] were specified for the experience, affection, and perceived capability variables towards the different Nature–Human–Society teaching areas. For every scale (Experience, Affection, and Perceived Capability), the data of the seven content domains were then z-transformed. Thus, it was possible to explore which content-domain expression was more or less pronounced compared to the total score of Nature–Human–Society (see Section 3.1). Which Nature–Human–Society topics among trainee teachers were generally most popular to teach and which were the least popular topics to teach was deduced based on the data of the individuals' ranking of the three favorite and the three disliked teaching topics (see Section 3.2).

The reasons why certain teaching topics were preferred or rejected were elicited with open-ended questions, so the freely formulated answers of the trainee teachers had to be analyzed qualitatively in terms of content [37]. The length of the answers varied between one and three statements per teaching topic, as it was up to the trainee teachers how many reasons they gave (a maximum of three). The categories for the reasons to like or dislike teaching topics were originally developed from the data material. For this purpose, the answers were examined individually and assigned to one or more categories (maximum three reasons per topic) depending on the content. The category names and definitions were gradually refined or supplemented during the analysis process in order to describe the category as accurately as possible for all topics, including indications of anchor examples. In this process, care was taken to ensure that the categories were separable; otherwise, categories were streamlined by combining categories with related content into larger categories. In the content coding, numbers were assigned to the answers so that a quantitative evaluation of the frequency of the individual categories could finally be made. In the second step of control analysis, which was conducted by a second researcher, the categories already developed were used to evaluate the data a second time. This double coding, independent from the first evaluation, was conducted to ensure the intersubjective traceability (reliability) of the category assignment. In this way, possible categories that may not have been assigned uniformly to an answer could be checked again and clarified together. After the categorization, the absolute frequencies per category were calculated to indicate how strongly the categories for liking and, respectively, disliking were used as arguments across all twelve teaching topics. Since the number of statements per teaching topic varied, the relative frequencies of categories were used to highlight the top three arguments per teaching topic in a figure. This made it possible to identify similar or dissimilar main arguments across the twelve topics (see Sections 3.3 and 3.4).

3. Results

3.1. Trainee Teachers' Expressions About Nature–Human–Society Domains

The internal consistencies of all Experience scales, Affection scales, and Perceived Capability scales ranged from 0.74 to 0.94. In addition to Cronbach's alpha, Table 1 also shows the mean scores and standard deviation for each individual subscale referring to the seven content domains of the Nature–Human–Society subject. The minimum and maximum of all subscales was between 2.65 and 4.34 (Likert scales ranged between 1 = low and 5 = high).

Table 1. Cronbach's alphas, means, and standard deviations of Experiences, Affections, and Perceived Capabilities (Per. Cap.) in the individual Nature–Human–Society domains; n = 220.

Content Domain	Experience α	Experience *M* (*SD*)	Affection α	Affection *M* (*SD*)	Per. Cap. α	Per. Cap. *M* (*SD*)
Social–ethical	0.841	3.66 (0.87)	0.922	4.07 (0.82)	0.885	3.67 (0.81)
Cultural–religious	0.807	3.41 (0.93)	0.908	3.73 (0.94)	0.869	3.56 (0.88)
Historical–political	0.794	3.23 (0.96)	0.897	3.64 (0.91)	0.838	3.35 (0.93)
Geographical	0.847	3.63 (0.88)	0.929	3.89 (0.80)	0.874	3.63 (0.84)
Economic	0.836	2.65 (0.89)	0.899	2.89 (0.89)	0.878	2.89 (0.89)
Physical–technical	0.869	2.79 (1.00)	0.937	3.01 (1.06)	0.738	3.20 (0.84)
Biological	0.828	4.09 (0.79)	0.926	4.34 (0.75)	0.889	4.01 (0.83)

To compare the characteristics in the different Nature–Human–Society domains, the standard values of Experience, Affection, and Perceived Capability scales were calculated and presented in Figure 2. It emerged that trainee teachers' experiences, affections, and perceived capabilities in the biological, social–ethical, and geographical areas were above average, while these values were clearly below average in the economics and physics–technology fields. The experiences, affections, and perceived capabilities regarding cultural–religious and historical–political domains were balanced equally, with a slight upward tendency for the former and a slight downward tendency for the latter.

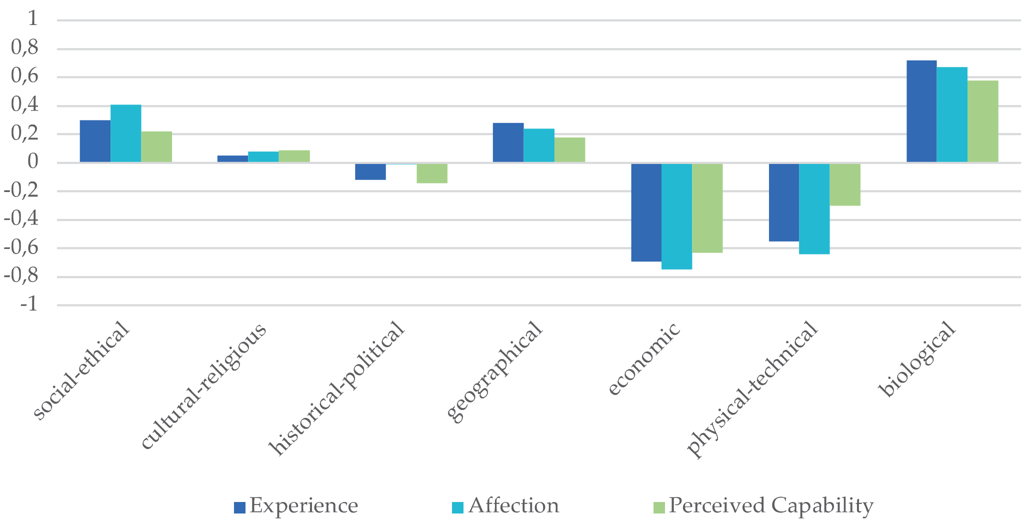

Figure 2. Standardized means of Experience, Affection, and Perceived Capability of all content domains; n = 220.

Furthermore, the three-bar expressions of each content domain indicate that trainee teachers' experience, affection, and perceived capability are quite homogeneously pronounced within the content domains.

3.2. Trainee Teachers' Popularity Ranking of Teaching Topics

From the list of twelve Nature–Human–Society teaching topics, the three most favored were "Earth, and how people live in other places" (110 favor votes), "Animals, woods, fields, ponds, and flowers" (97 favor votes), and "Life in earlier generations" (89 favor votes), while the three most disliked were "Substances and their properties" (125 dislike votes), "Technology, electricity, and inventions" (124 dislike votes), and "My hometown" (82 dislike votes). For each teaching topic, Figure 3 shows what percentage of students chose this topic as a favored or disliked teaching topic (each student was allowed to indicate three favored and three disliked topics). The results in Figure 2 also show that, generally, those teaching topics that were most popular also tended to receive the fewest unpopularity votes and vice versa. This also applies to the fourth-liked topic, "Being with others", where the popular/unpopular ratio shows a clear direction toward popular (74 votes in favor, 17 votes not in favor). Furthermore, the presented results evidenced which teaching topics are ranked in the middle of the popularity list, with the proportion for popular or unpopular being less than one-third and a more balanced relationship between popular/unpopular in each case, for example, "Thinking about oneself" (46 favor votes, 64 dislike votes), "Religions and traditions" (54 favor votes, 61 dislike votes), "Sun, moon, stars, and universe" (61 favor votes, 34 dislike votes), "How products were produced" (33 favor votes, 51 dislike votes), and "Water, air, weather, and stones" (30 favor votes, 45 dislike votes).

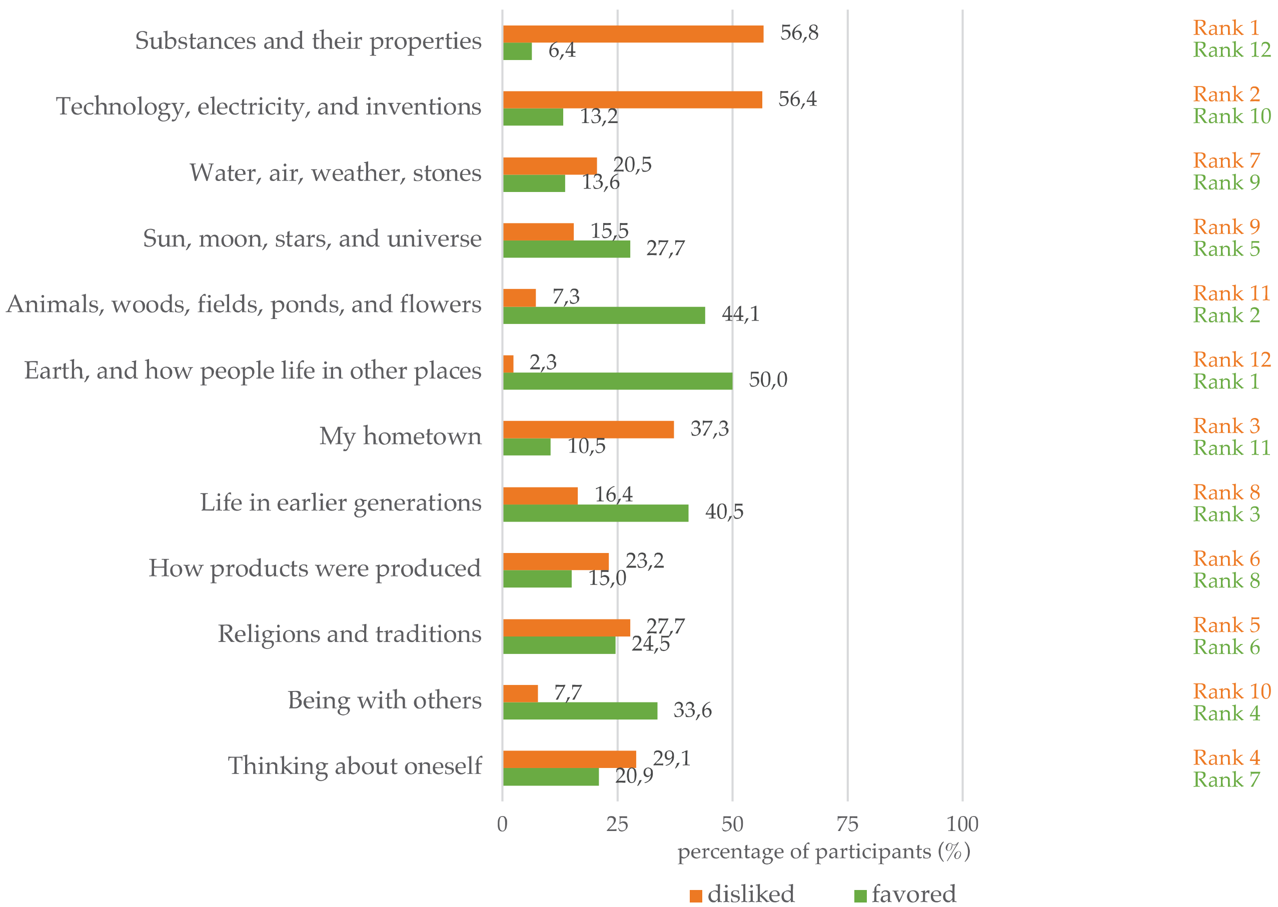

Figure 3. Percentages of participants who selected the various teaching topics of Nature–Human–Society subject as favored and disliked, respectively (n = 220, where each person could name a maximum of three favorite and three least favorite topics). In addition, the ranking of the respective teaching topics on the popularity scale is shown in green and that of the unpopularity scale is shown in orange.

3.3. Trainee Teachers' Arguments for Favoring Teaching Topics

Table 2 shows what kind of statements the trainee teachers made that led to the formation of twelve categories with arguments for liking a teaching topic. For each category, we specify the included statements and provides anchor examples.

Table 2. Category system for favoring topics. The categories are color-coded to match Figure 4.

	Category	Category Definition	Anchor Example
A	High relevance to everyday life	Statements describing knowledge of this topic as generally relevant to life.	*"It is important for life." "This is relevant to everyday life."*
B	Possibility of illustrative or action-oriented teaching	Statements focusing on favoring a lesson design.	*"Here the children can experience a lot for themselves in class."*
C	Personal interest	Statements expressing the trainee teacher's general interest in the topic.	*"I like that." "I have always enjoyed that."*
D	Promotion of prosocial behavior	Statements considering social skills to be important to promote.	*"Children should learn how to deal with others. Empathy is important."*
E	Significant shift in perspective	Statements expressing that children should broaden their own horizons.	*"Children should look beyond their usual sphere of experience."*
F	Important to build up background knowledge	Statements that children should develop a deeper understanding.	*"It is important that children understand why/how. . ."*
G	To build up awareness and appreciation	Statements of ethical awareness and appreciation development.	*"These are topics where children need to be sensitized."*
H	Important for personality development	Statements referring to the importance of self-reflection and self-esteem.	*"Children should reflect themselves." "They should build self-confidence."*
I	Value of sustainability and environmental protection	Statements valuing the protection of nature and sustainable development.	*"Education for environmental sustainability is important."*
J	Children's interest and experiences given	Statements showing that children are intrinsically motivated.	*"Because that fascinates children." "Because children like to do it."*
K	Fascination for the unknown	Statements indicating it is exciting to learn more about something unknown.	*"I would like to know more about the unknown/unexplored."*
L	High ability—self-concept	Statements that they feel competent about the issues of this topic.	*"I know this [content area] well." "I am confident that I can teach it."*

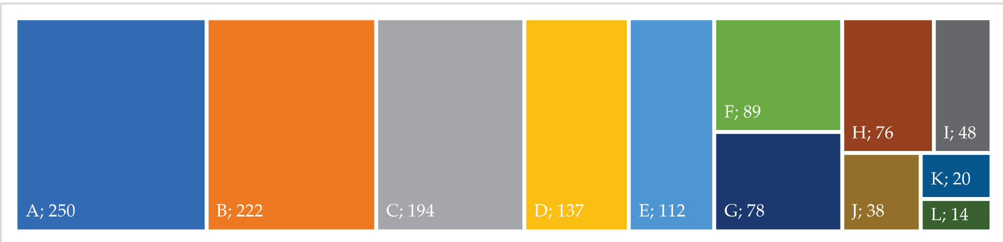

Figure 4. Frequency of statements in the various categories about liking teaching topics; N = 1278.

A total of 1278 category assignments were made. The most frequently cited reason for choosing a topic as one of the three favorite teaching topics was "High relevance to everyday life" (A), followed by "Possibility of illustrative or action-oriented teaching" (B) and "Personal interest" (C). Further reasons, according to the frequency with which they were mentioned, were "Promotion of prosocial behavior" (D), "Significant shift in perspective" (E), "Important to build up background knowledge" (F), "To build up awareness and appreciation" (G), "Important for personality development" (H), "Value of sustainability and environmental protection" (I), "Children's interest and experience given" (J), "Fascination for the unknown" (K), and "High ability self-concept" (L). The exact number of mentions assigned to these categories is shown in Figure 4.

For each teaching topic, Figure 5 indicates which three categories of arguments for liking a certain teaching topic were most pronounced. The top three categories represent between 55 and 100 percent of the trainee teachers' statements in each teaching topic. This means that for some teaching topics, these three categories have almost a full informative value, while for other teaching topics, the reason for popularity is more multi-layered than what is covered by the three categories. The average coverage for reasons in the top three categories is 74 percent.

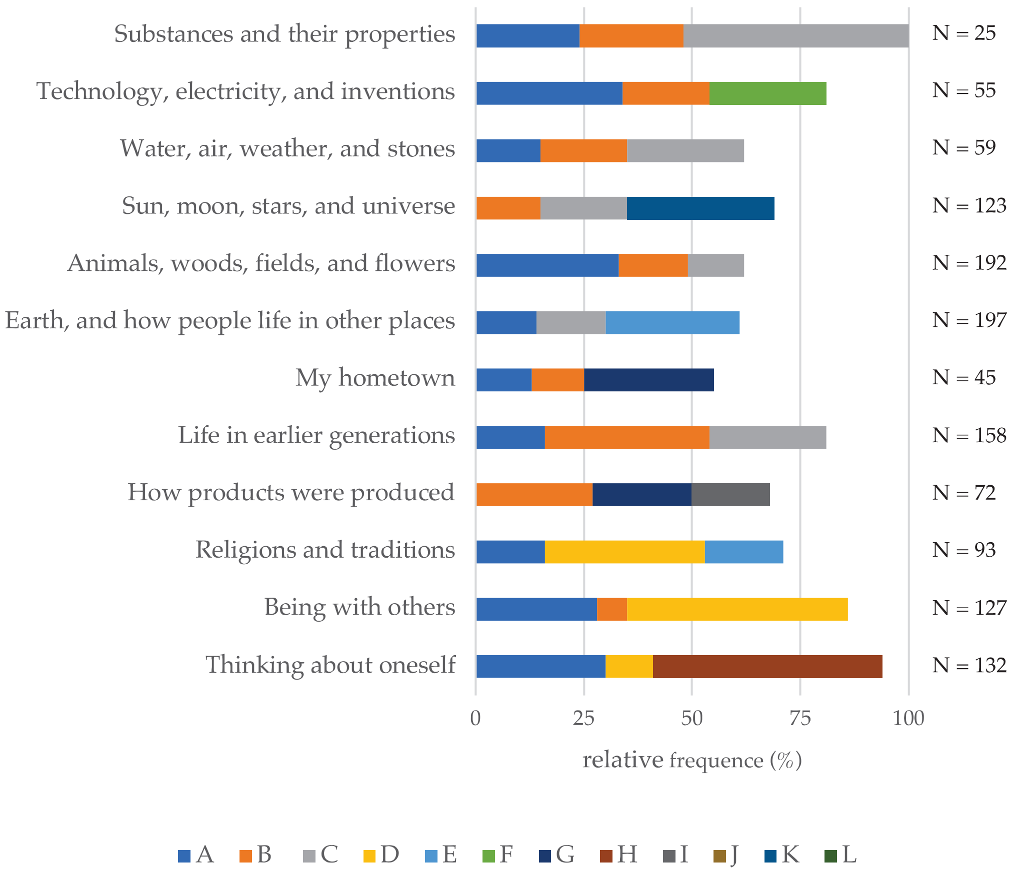

Figure 5. The relative frequency of the top three arguments (categories A–L) for liking a certain teaching topic. N indicates the total number of category statements given per teaching topic.

Focusing on the second research question, we looked at the distribution of the categories across all teaching topics, showing in which teaching topic the categories appeared as the top three arguments and in which they did not. The category "High relevance to everyday life" (A) made it most often into the top three arguments, with the exception of the teaching topic "Sun, moon, stars, and universe" and "How products were built". The second category most often chosen, "Possibility for illustrative or action-oriented teaching" (B), was found among the top three arguments for liking a teaching topic, except for the teaching topics "Religions and traditions" and "Thinking about oneself". The category "Personal interest" (C) was also in the top three arguments for many teaching topics but not for "Technology, electricity, and interventions", "My hometown", "How products were built", "Religions and traditions", "Being with others", and "Thinking about oneself". The category "Promotion of prosocial behavior" (D) was present among the top three arguments for liking the teaching topics "Religions and Traditions", "Being with others", and "Thinking about oneself". The category "Significant shift in perspective" (E) seemed to be a frequent argument, especially for the topics "Earth, and how people live in other places" and "Religions and traditions".

The category "Important to build up background knowledge" (F) only made it into the top three arguments for one topic, namely "Technology, electricity, and interventions". The category "To build up awareness and appreciation" (G) is represented twice among the top three arguments, namely in the teaching topics "My hometown" and "How products were built". The category "Importance for personality development" (H) was among the top three arguments for the topic "Thinking about oneself". The category "Value of sustainability and environmental protection" (I) appeared in only one topic in the top three arguments, namely "How products were built". The category "Children's interest and experiences given" (J) did not make it into the top three arguments for any of the teaching topics but was most likely to play a role in favoring the topics "Animals, woods, fields, and flowers" and "Sun, moon, stars, and universe". The category "Fascination for the unknown" (K) was particularly frequent in the topic "Sun, moon, stars, and universe" and was also among the top three arguments. The category "High ability self-concept" (L) did not emerge in the top three arguments in any of the teaching topic fields but appeared infrequently in the topics "Sun, moon, stars, and universe", "Animals, wood, fields, and flowers", and "Water, air, weather, and stones".

In the following list, only the most evident argument for each teaching topic was highlighted and illustrated with examples from their respective topic. The description of the main argument for preferring a topic is listed according to its popularity ranking:

- The teaching topic "Earth, and how people live in other places", which emerged as the most popular topic to teach among the trainee teacher group, was justified in its popularity most often by a "Significant shift in perspective" (category E), i.e., "*It should be shown to the children that there is not only Switzerland. Getting to know other cultures and habitats, and thus broadening their horizons is enriching. It gives them the opportunity to question what they are used to.*"
- The most common reason for preferring to teach the second favorite topic, "Animals, woods, field, ponds, and flowers" was the "Personal interest" (category C), i.e., "*Because I am very interested in animals and how to deal with them. I also like being in nature, observing the landscape and agriculture. But most of all, I love animals. I have some myself. Biology was my favorite subject at school.*"
- For the third favorite teaching topic, "Life in earlier generations", the argument of "High relevance to everyday life" (category A) was most often crucial for favoring to teach it, i.e., "*To understand today's state of affairs, I think it is necessary to take a look at the past. The past has influenced the present and will also influence the future. It is important that children also know what the world was like when they were not around. Thus, the children see how the world has changed and is still changing.*"
- The popularity of teaching the fourth-ranked topic, "Being with others", was most often justified with the "Promotion of prosocial behavior" (category D), i.e., "*Children will always have to deal with different people, so they should learn how to approach others politely and openly. Learning to respect each other is also beneficial to the classroom climate.*"
- For the fifth-ranked teaching topic, "Sun, moon, stars, and universe", the argument of "Personal interest" (category C) was most often dominant for favoring to teach it, i.e., "*I find it fascinating how small we are compared to the universe. The darkness of the universe is beautiful on one side and scary on the other. I personally find the universe extremely exciting and wanted to study astrophysics once.*"
- The popularity of the teaching topic in sixth place in the popularity list, "Religions and traditions", was justified most often with "Promotion of prosocial behavior" (category D), i.e., "*I would like to teach it to convey understanding and acceptance for other religions and customs so that perhaps at some point issues such as racism or hatred between different religions lose their relevance and we learn to live and let live.*"
- The top argument for liking to teach the seventh-favorite topic, "Thinking about oneself", was that it is "Important for personality development" (category H), i.e., "*So that the children get time to get to know themselves, find out what they can do well and thereby possibly gain greater self-confidence. And then also dare to speak their mind in this world.*"
- The eighth-ranked topic, "How products were produced", was most often liked due to its possibility "To build up awareness and appreciation" (category G), i.e., "*Because we people often do not know the process behind it and rarely deal with it. This could promote consumer awareness. Children should understand, for example, that there are many production*

steps and transportation routes behind a t-shirt that we wear and that cheap t-shirts are linked to questionable working conditions and low wages."

- The teaching topic "Water, air, weather, and stones" was ranked in ninth place and was liked by trainee teachers most often due to "Personal interest" (category C), i.e., "*There are exciting natural phenomena to this. I am interested in it. Even as a child I found it positive in class. Recently I have delved more deeply into this content and again have found it pleasurable.*"
- The tenth-ranked teaching topic, "Technology, electricity, and inventions", was favored to be taught most often because it is "Important to build up background knowledge" (category F), i.e., "*We live in a modern technological world, which is why I think it is also important to understand the background of new technology. Children should develop an understanding of how such machines/devices etc. work.*"
- The most common reason for liking the eleventh-ranked teaching topic, "My hometown", was the "Possibility of illustrative or action-oriented teaching" (category B), i.e., "*Even in their own town there is still a lot for children to discover. You can make excursions nearby, such as visiting a farm. Children's learning can take place outside the classroom with this theme.*"
- The twelfth and thus last-ranked teaching topic in the popularity list was "Substances and their properties". It was liked most often from trainee teachers with a "Personal interest" (category C), i.e., "*I am interested in chemistry. Personally, I find it very interesting to do experiments.*"

Generally, it must be mentioned that the number of arguments on the teaching topics naturally varies, as certain topics appealed to more trainee teachers (see Figure 3) than others and were therefore subject to more or less frequent argumentation by trainee teachers (see Figure 5). When a person expressed a preference for a particular topic, the average number of reasons given for this preference of the categories described above was 1.94.

In total, only three arguments of categories were found in the sample for liking the teaching topic "Substances and their properties" (expressed categories: A–C), five categories for liking the teaching topic "Thinking about oneself" (expressed categories: A–C, F, and G), seven categories for liking the teaching topics "Water, air, weather, and stones" (expressed categories: A–E, H, and J) and "Technology, electricity, and inventions" (expressed categories: A–E, H, and J), and eight categories for liking the teaching topic "Being with others" (expressed categories: A–C, E–G, I, and K). Furthermore, nine categories were classified for the teaching topics "Life in earlier generations" (expressed categories: all except E, G and L), "My hometown" (expressed categories: all except F, G, and L), "Animals, woods, fields, ponds, and flowers" (expressed categories: all except F, G, and L), and "Sun, moon, stars, and universe" (expressed categories: all except F, G, and K). Finally, ten categories were assigned for liking the teaching topics "How products were produced" (expressed categories: all except D and F) and "Earth, and how people live in other places" (expressed categories: all except D and G), and eleven categories for liking the teaching topic "Religions and traditions" (expressed categories: all except G).

Based on these results, it can be said that teaching topics that were generally extremely popular and therefore subject to justification by many trainee teachers did not always have more arguments than those topics that were less popular. Rather, it seemed to depend on how many different arguments were expressed by trainee teachers.

3.4. Trainee Teachers' Arguments for Disliking Teaching Topics

Table 3 lists the categories that give arguments for why trainee teachers disliked certain teaching topics. The nine-section category system was developed on the basis of the trainee teachers' statements and was illustrated in more detail in the table with content definitions and anchor examples.

Table 3. Category system for arguments as to why a teaching topic is disliked. The categories (a–i) are color-coded to match Figure 6.

	Category	Category Definition	Anchor Example
a	Personal disinterest	Statements expressing the trainee teacher's general disinterest.	*"[It] doesn't really interest me." "I am not interested in that".*
b	Lack of conceptual knowledge	Statements of lack of knowledge or describing it as difficult and complex.	*"I lack the knowledge here." "I do not know the field well. . ."*
c	Lack of ideas for teaching	Statements focusing on the lack of ideas/possibilities for lesson design.	*"I don't see how you could teach this in an exciting way."*
d	Lack of fit for age group	Statements that the topics are too difficult or uninteresting for children.	*"Is still too difficult for the age group." "Children are not interested in that."*
e	Low ability—self-concept for teaching	Statements that they do not feel competent about this issue.	*"I wouldn't know how to teach this." "I don't trust myself to do that."*
f	Lack of relevance for everyday life	Statements that knowledge of this topic is generally not relevant to life.	*"There are more important issues." "I don't see its relevance to everyday life".*
g	Part of extracurricular or general education	Statements referring to it as a general or extracurricular education topic.	*"This topic is the parents' responsibility." "Can be addressed elsewhere".*
h	Afraid of delicate topic	Statements that topics are delicate to address, because they are very personal.	*"It is a sensitive topic. I am afraid of hurting someone's feelings."*
i	Lack of science-based facts	Statements of beliefs that the topic is insufficiently knowledge-based.	*"Knowledge is still changing in this field." "It lacks scientific theories."*

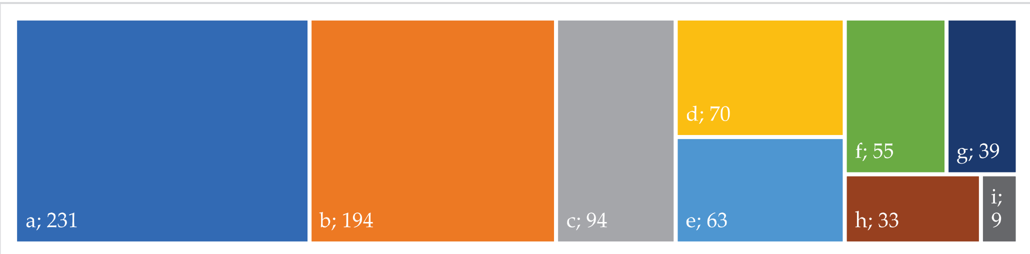

Figure 6. Frequency of statements in the various categories about disliking teaching topics; N = 788. The letter indicates the category and the number represents the frequency of this category.

There are four categories of arguments for disliking a teaching topic that expressed the opposite poles of the arguments designated for liking teaching topics, namely "Personal interest" vs. "Personal disinterest", "Possibility of illustrative or active-oriented teaching" vs. "Lack of ideas for teaching", "High ability self-concept" vs. "Low ability self-concept", and "High relevance to everyday life" vs. "Lack of relevance for everyday life".

A total of 788 category assignments were made for the arguments used by trainee teachers to justify their three least favorite teaching topics. The most common reason for disliking a teaching topic was "Personal disinterest" (a), followed by "Lack of conceptual knowledge" (b) and "Lack of ideas for teaching" (c). Other reasons are listed here according to how frequently they were mentioned (for the exact frequency of mention, see Figure 6): "A lack of fit for age group" (d), "Low ability self-concept for teaching" (e), "Lack of relevance to everyday life" (f), "Part of extracurricular or general education" (g), "Afraid of delicate topic" (h), and "Lack of science-based facts" (i).

Figure 7 shows, for each teaching topic, which three categories of arguments for disliking a particular teaching topic were most prevalent. These extracted top three categories of dislike represent between 54 and 100 percent of the statements made by trainee teachers in each topic area. Accordingly, for some teaching topics, partially complete information was already available in these three categories, while for other teaching topics, the reasons for unpopularity are more complex than was covered by the three categories. Including the three categories presented for each topic, the reasons for unpopularity for all the topics are, on average, 78 percent.

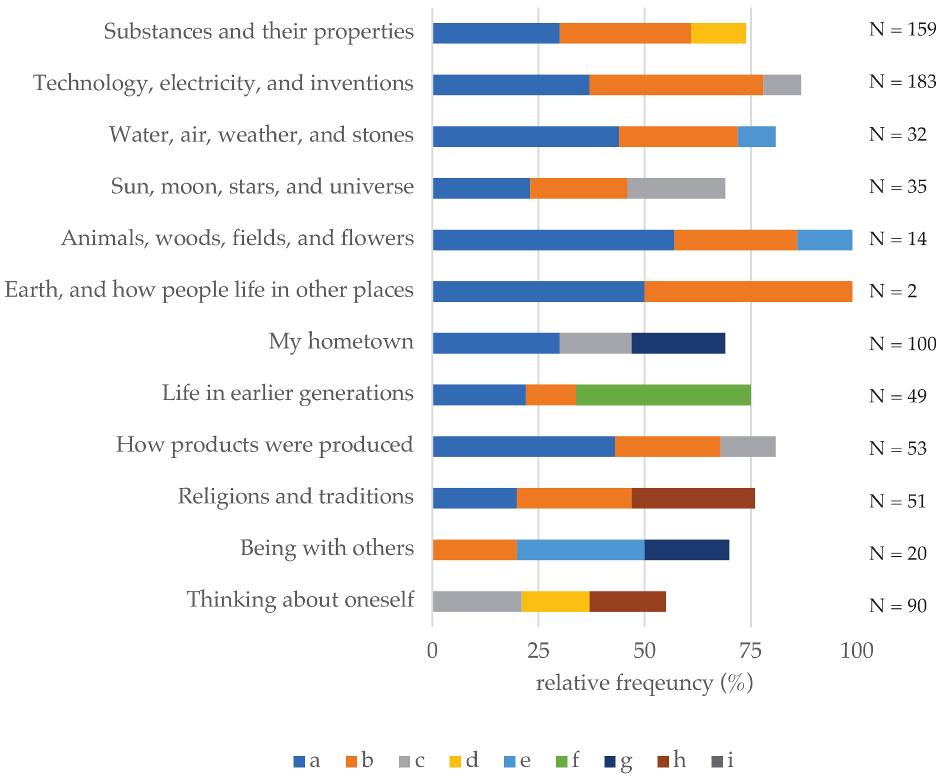

Figure 7. The relative frequency of the top three arguments (categories a–i) for disliking a certain teaching topic. N indicates the total number of category statements given per teaching topic.

From the colors of the bars, it becomes clear that the two most frequently represented categories are also among the top three arguments for disliking almost all topics. The argument "Personal disinterest" (a) appears for 10 out of 12 topics in the top three, but the teaching topics "Being with others" and "Thinking about oneself" do not. Likewise, the argument "Lack of conceptual knowledge" (b) is in ten of the twelve topics in the top three, but not among the teaching topics "My hometown" and "Thinking about oneself". The argument "Lack of ideas for teaching" (c) is one of the three dominant reasons for disliking five out of twelve teaching topics, namely: "Technology, electricity, and innovations", "Sun, moon, stars, and universe", "My hometown", "How products were produced", and "Thinking about oneself". The category "Lack of fit for age group" (d) is among the top three arguments for disliking the teaching topics "Substances and their properties" and "Thinking about oneself", while the category "Low ability self-concept (to teach)" (e) is the reason for disliking "Water, air, weather, and stones", "Animals, woods, fields, and flowers", and "Being with others". Only one teaching topic, the category "Lack of relevance for everyday life" (f), was dominant among the top three arguments for disliking teaching topics. The category "Part of extracurricular or general education" (g) was often the main reason for disliking the teaching topics "My hometown" and "Being with others". As a crucial category in the top three, the argument "Afraid of delicate topic" (h) appeared for disliking the teaching topics "Religions and traditions" and "Thinking about oneself". For the sake of completeness, it must be stated that the category "Not enough science-based facts" (i) did not make it into the top three for disliking any topic. This argument was found, for example, in justifying the unpopularity of the teaching topics "Thinking about oneself" and "Religions and traditions".

Among the list of unpopular teaching topics, starting with the most unpopular one, the following were highlighted as the crucial reason for each teaching topic, illustrated by a concrete example:

- The least popular topic was "Substances and their properties" and the justification for disliking it was most often attributed to a "Lack of conceptual knowledge" (category b), i.e., "*Chemistry has never been my strong point. I have the feeling that I would then explain a lot of things incorrectly.*"

- The second least popular topic, "Technology, electricity and inventions", was also justified as disliked most often because of a "Lack of conceptual knowledge" (category b), i.e., "*I don't know very much about it; it's not my field of expertise. Even when I was in school, I didn't understand electricity or physics.*"
- The most frequent reason for not liking the third least popular topic, "My hometown", was "Personal disinterest" (category a), i.e., "*Personally, I have little interest in it. There are more exciting topics for me. Switzerland is about the same everywhere. Foreign environments arouse my interest more. That's why I don't want to teach it, because anything you don't enjoy is harder to get across as a teacher.*"
- The fourth-ranked teaching topic, "Thinking about oneself", was most often not liked because of a "Lack of ideas for teaching" (category c), i.e., "*I can't imagine exactly how one would teach this. Does this even work as a Nature-Human-Society teaching topic?*"
- The fifth-ranked teaching topic, "Religions and traditions", was frequently not liked as a subject matter due to the category "Afraid of delicate topic" (category h), i.e., "*I think this is a very delicate issue and I imagine that it would be a great challenge to respond fairly to all students and their faith. From my own experience, I know that this topic requires a lot of sensitivity (can degenerate into 'my religion is better than yours').*"
- The sixth-ranked teaching topic, "How products were produced", was most often not liked by trainee teachers due to "Personal disinterest" (category a), i.e., "*I don't find it that interesting. In the lessons, I would not go into too much detail about the production steps of goods, because that would be too dry for me.*"
- In addition, the seventh-ranked teaching topic, "Water, air, weather, and stones", was most often disliked due to a "Personal disinterest" (category a), i.e., "*I'm less enthusiastic about this topic myself, which the children would then probably notice. Personally, stones and crystals hardly interest me.*"
- The eighth-ranked teaching topic in the unpopularity list was "Life in earlier generations" and was justified most often due to a "Lack of relevance to everyday life" (category f), i.e., "*It is the past. We live in the here and now and I think the future is generally more important. Therefore, in my opinion, the past is not so relevant to teach, for example, the Middle Ages a whole school year.*"
- In the ninth-ranked teaching topic, "Sun, moon, stars, and universe", the arguments "Personal disinterest" (category a), "Lack of conceptual knowledge (category b), and "Lack of ideas for teaching" (category c) were equally cited as the most common reason to dislike teaching this topic, i.e., "*Because of lack of interest and knowledge on my part. I would not know how to explain it best, since the content is difficult to illustrate*."
- The tenth-ranked teaching topic, "Animals, woods, fields, ponds and flowers", was most often disliked due to a "Personal disinterest" (category a), i.e., "*I am not really an animal lover. I have little interest in them, and I am even afraid of some animals.*"
- The disliking of the eleventh-ranked teaching topic, "Being with others", was justified most often with a "Low ability self-concept for teaching" (category e), i.e., "*I find this topic difficult to teach. I do not know if I could teach it.*"
- The least unpopular topic, "Earth, and how people live in other places", was consequently last ranked on the unpopularly list and there were only two arguments for disliking expressed, namely "Personal disinterest" (category a), i.e., "*I am not interested in this.*" and "Lack of conceptual knowledge" (category b), i.e., "*I have too little knowledge about life in other countries, no experiences, no real knowledge (I have never been there).*"

For the list of reasons for disliked teaching topics, it must also be mentioned that the number of justifications per teaching topic naturally varies, since certain topics are disliked by decidedly many trainee teachers and others by rather few (see Figure 3) and therefore subject to more or less frequent argumentation by trainee teachers (see Figure 7). When trainee teachers expressed a dislike of a particular teaching topic, the average number of reasons given for this dislike was 1.17 categories of those described above.

Overall, it was noted that not every justification was used for every teaching topic. There were teaching topics where the same few reasons were always given, and others where the reasons were more varied. In total, two argumentation categories for the topic were found in "Earth, and how people live in other places" (expressed categories: a and b), three categories for the topic "Animals, woods, fields, and flowers" (expressed categories: a, b, and d), six categories for the topic "How products were produced" (expressed categories: a–e and g), seven categories for the topic "Sun, moons, stars, and universe" (expressed categories: a–e, g, and i), eight categories for the topics "Being with others" (expressed categories: all except category d), "Life in earlier generations" (expressed categories: all except category i), "My hometown" (expressed categories: all except category i), and all nine categories for the topic "Thinking about oneself" (expressed categories: all).

4. Discussion

Guided by the open question of what arguments trainee teachers give for liking or disliking certain teaching topics in the Nature–Human–Society subject, this research was conducted with a study cohort of first-year students. The sample of this study can be considered representative of the typical student cohorts of this university of teacher education [32], as the typical gender ratio is represented quite well, and the sample's Nature–Human–Society preferences and characteristics were similar to the results of other studies in terms of prior experience, affection, and perceived capability [22–26]. It became clear once again that there are two subject areas in Nature–Human–Society that the trainee teachers, compared to other topics, have not had such good experiences with, do not find emotionally appealing, and do not feel confident enough to teach. These areas are economics and physics–technology. Conversely, biological and social–ethical topics seem to have a positive status among the trainee teachers, both in terms of experience, affection, and perceived capability. The geographical teaching topic "Earth and how people live in other places" seems to combine trainee teachers' biological and social–ethical orientation best, as it was clearly the most popular topic to teach, followed by the biological teaching topic "Animals, woods, ponds, and flowers". At the bottom of the popularity scale for teaching topics were object-related topics, i.e., topics from the field of inanimate nature and technology, which is not surprising as trainee teachers' interest structure is known to be more person-orientated [26]. These results reflected the findings of other quantitative studies quite well [22–26].

However, the perspective of the children was not sufficiently reflected in this view of the trainee teachers. While the trainee teachers' positive attitudes towards topics of animate nature are in line with the interests of the children, the negative attitude of the trainee teachers towards topics of inanimate nature clashed with the interest preferences of the children, who expressed a strong interest in this area. This suggests a mismatch between pupils and teachers and can ultimately mean that the topics that are of most interest to children (see Figure 1) [12] are not given sufficient time and importance in lessons because of their teachers' negative attitudes towards the abovementioned topics. Thus, the learning processes and outcomes of pupils can be compromised if teachers systematically neglect certain topics because of their personal outlook, even if the curriculum provides for a wide range of content [4,38–40]. Therefore, it was also important to explore the backgrounds that shape the attitudes of pre-service teachers.

The research question "How do trainee teachers justify their likes and dislikes for Nature–Human–Society teaching topics?" was answered in a differentiated way for twelve different teaching topics in this study. Even if there were teaching topics that were generally more (or less) popular among the trainee teachers, there was at least a small group of trainee teachers for each of those twelve teaching topics who ranked these Nature–Human–Society topics among their top three favorite (or least favorite) topics to teach. Thus, according to this survey, there are reasons to like or dislike a teaching topic for all twelve topics of

Nature–Human–Society. However, it must also be noted, as a limitation of this study, that the empirical evidence of the argumentation was not equally high for all teaching topics, as there were topics that were only liked or disliked by a few and therefore not based on a large number of trainee teachers. Research desiderata would therefore include further qualitative surveys specifically on those teaching topics of Nature–Human–Society that are named as popular or unpopular by particularly few trainee teachers in order to increase the informative value of these data.

The most common reasons given for wanting to teach a topic were because it is highly relevant to everyday life and because it can be taught with illustrative materials or out of personal interest. Personal disinterest, a lack of conceptual knowledge, or a lack of teaching ideas, on the other hand, were the most common reasons for not liking certain teaching topics. It is notable that the statements about which issues of these topics they felt competent were underrepresented in the arguments for liking teaching topics. At the same time, the conviction that they do not have enough knowledge about these content areas seemed to have played a decisive role in the arguments for disliking a teaching topic. This finding is important because it highlights the need to work on trainee teachers' subject knowledge during their teacher training and also on didactic knowledge to implement this content in an appropriate way for children. Conversely, the findings of this study have made it clear that a positive attitude towards certain teaching topics is not necessarily related to the trainee teachers' perceptions of their competence in those subject areas. In other words, just because a teacher has a positive attitude towards a subject area does not mean that they feel confident to teach that subject area. This also suggests that it is generally important to create a teacher trainee environment where students feel supported and encouraged to develop their teaching skills, since trainee teachers' attitudes are not the only factor that determines pupils' learning [4,18,30,38,39,41]. However, it is known from the literature that the areas of personal interest are often associated with increased knowledge in this area, as people are more concerned with issues that interest them [42]. Therefore, the argument of an interesting topic can also be seen indirectly as an indicator that trainee teachers have more knowledge or experience in this content area. A previous study [23], which objectively recorded the general knowledge in specific areas, showed nevertheless that many trainee teachers who showed an interest in a particular Nature–Human–Society topic had no increased declarative knowledge of it. An effective difference in content knowledge was evident only in the comparison group of trainee teachers who favored or did not favor physics. Overall, according to the present study, the value-appreciative appraisal of the teaching topic, the teaching opportunities, and the personal interest approach seem to characterize teaching preferences.

After the analysis of all the inductively obtained arguments for liking and disliking certain teaching topics, an attempt was made to relate them theoretically. The three dimensions of attitude (Cognitive Beliefs, Affective States, and Perceived Control) according to the theoretical framework of Van Aalderen-Smeets and colleagues [30] seemed to be quite suitable for classifying all identified arguments (see Table 4). Only the dimension of Affective States had to be expanded with the Affective Access concept because the category of interest/disinterest found was broader as a concept than as a pure emotion. However, let us examine the individual dimensions one by one.

The first dimension we explored was Cognitive Beliefs. According to Van Aalderen-Smeets and colleagues' [30] theoretical framework, the cognitive dimension of attitude encompasses the evaluative thoughts and beliefs that a person has about the object of the attitude. This includes, for example, the perceived relevance or importance of the topic for society and daily life, as was also often found in the trainee teachers' arguments in this study. Trainee teachers mentioned that pupils can gain various benefits from dealing with these teaching topics, such as sensitive behavior towards the environment and other people. Thus, it became clear in this study that trainee teachers believe that the environment and the interplay of the self with others are fundamental. Obviously, the prospective teachers of the Nature–Human–Society subject see their task as teaching children values that ensure the preservation of the environment and social coexistence, thus the livelihood and well-being of people. It was remarkable that only the teaching topic "Sun, moon, stars, and universe" had no main argument for liking which was justified by being useful in people's lives. The trainee teachers probably do not see any direct benefits in having knowledge about celestial bodies as opposed to earlier times in history when celestial bodies were used, for example, for orientation or as an early form of the calendar. Generally, it can be stated from the literature that newer technologies have changed the significance of knowledge about the celestial bodies for humans' daily life, although there is clearly an awareness in society that without the sun, for example, there would be no life on earth and that the sun is also important as a renewable energy source [43]. Another trainee teacher's argument that can be counted among the cognitive beliefs of relevance attribution is that children's interests and experiences are assumed for a particular subject area. It is therefore important to the trainee teachers that the topic is of interest to the children, that it has something to do with their immediate environment, and that children have already encountered it. A lack of topic relevance would thus be equated with a lack of child interest and motivation. If the topic is not relevant enough for children, then it does not arouse the interest and motivation necessary for learning, or if the topic has no connection to their lifeworld, then they cannot establish a personal context. Furthermore, there is the assumption that certain subject areas are not the responsibility of schools. In addition, some trainee teachers do not see much relevance in teaching some assigned tasks of the Nature–Human–Society subject because they believe that children can gain this knowledge and skill elsewhere. At the same time, the belief of "Part of extracurricular or general education" highlights the potential lack of understanding or imagination regarding what this topic entails or could signify within the classroom setting. Here, teacher training can play a crucial role in providing guidance and shedding light on the intricacies of these subject areas.

Table 4. Assignment of the inductively formed categories to the three attitude dimensions of the theoretical framework of [30]. Note: the attitude dimension Affective State was adapted with the term Affective Access.

Dimension	Arguments for Liking	Arguments for Disliking
Cognitive Beliefs	▪ High relevance to everyday life ▪ Promotion of prosocial behavior ▪ Significant shift in perspective ▪ Important to build up background knowledge ▪ To build up awareness and appreciation ▪ Important for personality development ▪ Value of sustainability and environmental protection ▪ Children's interests and experiences given	▪ Lack of relevance for everyday life ▪ Part of extracurricular or general education ▪ Lack of science-based facts ▪ Lack of fit for age group
Affective Access	▪ Personal interest ▪ Fascination for the unknown	▪ Personal disinterest ▪ Afraid of delicate topic
Perceived Control	▪ Possibility of illustrative or action-oriented teaching ▪ High ability-self concept	▪ Lack of ideas for teaching ▪ Lack of conceptual knowledge ▪ Low ability self-concept for teaching

According to Van Aalderen-Smeets and colleagues' [30] theoretical framework, another attribute of Cognitive Beliefs is the perceived general (and not subjective) difficulty of teaching that topic. It refers to a difficulty that is inherent in the task or situation itself and is not dependent on the individual's perception or experience. This form of cognitive belief could be identified once in the argument of assuming a general lack of established knowledge in this area. The belief that it is difficult to teach something about which there are not enough facts was not mentioned frequently in this study, but it showed that trainee teachers recognize either a difference in the quality of data, evidence, and regularities across some sciences (i.e., religion studies vs. physics) or that they are simply not yet familiar enough with the theoretical concepts behind certain topics (i.e., thinking about oneself) in order to recognize them. Furthermore, the argument that the topic is not appropriate for an age group can also be seen as a cognitive belief of general difficulty. The expressed beliefs of a lack of fit for the age group are understood primarily in the sense that the children do not have the cognitive maturity to understand the complex topics of the content, which can lead to difficulties in learning during lessons. In both cases of these beliefs of perceived difficulty, it is important that the teacher training shows its students what these teaching topics mean in kindergarten and primary school and how they can be dealt with in the classroom so that learning can take place. For example, getting to know the curriculum and the differentiated competence expectations it contains for the different age groups will certainly help them to better grasp the subject matter [1,10,11].

A further possible attribution of Cognitive Beliefs according to this theoretical framework [30], namely convictions about gender-specific differences in people's abilities, was not found in this study, but this result can be evaluated as positive. This means that there were no gender-stereotypical ideas among the trainee teachers that would have an influence on their teaching preferences. This result contradicts the findings of other studies that have found gender-specific beliefs in teachers, such as the belief that science topics are more suitable for boys than for girls [30].

The second dimension of the theoretical category assignment we investigated was Affective Access. In the original theory framework [30], Affective States was mentioned as another attitude dimension. The term Affective States is considered to refer to the feelings and moods that a person experiences in relation to the object of the attitude, strictly speaking, in teaching certain content. Since the participants surveyed were first-year students and not working teachers or those with professional experience, the concept had to be adapted somewhat in the theoretical classification of trainee teachers' arguments. The term Affective Access seemed to be appropriate and accurate for the theoretical classification of certain inductively formed categories in this study that implicated emotional valences. Both positive and negative emotions, such as curiosity or fear, can be read from the trainee teachers' arguments. In this context, we can recall that emotions always influence the readiness to act. In the case of positive emotions, they lead towards an object, and in the case of negative emotions, they lead to distancing from the object [44]. With the category of interest (and disinterest), however, we found a concept that is broader than just a feeling or an emotion as it involves cognitive aspects as well. Therefore, personal interests and disinterests describe more fully the (missing) affective access for teaching a certain topic in teachers as individuals, not the emotions arising during teaching as was defined with affective states. Nevertheless, the term interest generally implicates feelings of stimulation and joy; it is the feeling of engagement. Thus, in the case of teaching certain topics, an interest-orientated action is always associated with positive emotional valences. It also contains a sense of self-determination, i.e., teachers feel free from external constraints because they have the feeling that they can do what they want to do. The cognitive representations of the object of interest, including the knowledge of possible courses of action in this subject area, are emotionally positive. It is important to note that the emotional tone relates not only to the past but also to future confrontations with objects, i.e., people expect an interest-oriented activity to evoke pleasant experiential qualities [45]. This implies that the (development of) interest in particular teaching content or methods can foster a deeper level of engagement in the teaching practice of future teachers. Osborne and colleagues [46] mentioned, for example, that a crucial characteristic of a good science teacher is being interested and enthusiastic about science.

The third dimension of the theoretical category assignment we inspected was Perceived Control. According to the theoretical framework [30], perceived control derives from beliefs of self-efficacy [47] and perceived dependence on contextual factors, leading to the teacher's impression of being able to control the teaching situation. This concept reflects the subjective beliefs and feelings of the individual about internal and external obstacles. In this study, this dimension could be identified in statements of personal inability and ability, as well as of subjective convictions that lessons can or cannot be conducted due to external reasons such as (missing) possibilities for illustration and action-oriented lesson organization. These trainee teachers' arguments expressed a basic need for motivational behavior control, namely the need to experience competence, as Deci and Ryan [16] defined it, i.e., to experience oneself as capable of acting and coping with foreseeable challenges. As trainee teachers' assessments relate to future actions, they imply confidence in one's own ability to learn and develop in order to be able to cope with such teaching situations later on [45]. In this context, the students seemed to assess their prerequisites differently in the various teaching topics. In some subject areas, they do not trust themselves due to a lack of knowledge in the subject area [48] or a lack of child-appropriate teaching ideas. There seems to be a perception that if illustrative and action-oriented teaching ideas are known, teaching can be mastered, as it is probably assumed that children can then be brought up to their performance level and motivated in their learning and that the lessons will then run smoothly. However, pedagogical content knowledge contains more than just an understanding of appropriate learning tasks for certain teaching topics and effective methods for implementing them. For example, it also includes knowledge about typical ideas of children regarding teaching topics and explanatory knowledge, which is distinct from another area of professional knowledge, namely content knowledge, which is defined as a deep understanding of the subject content [41]. Teacher education needs to foster students' growth in all these areas, nurturing their aspiration to teach.

The pie charts in Figure 8 show how large the proportion of these three attitude dimensions is when trainee teachers name reasons for liking or disliking a teaching topic in the Nature–Human–Society subject.

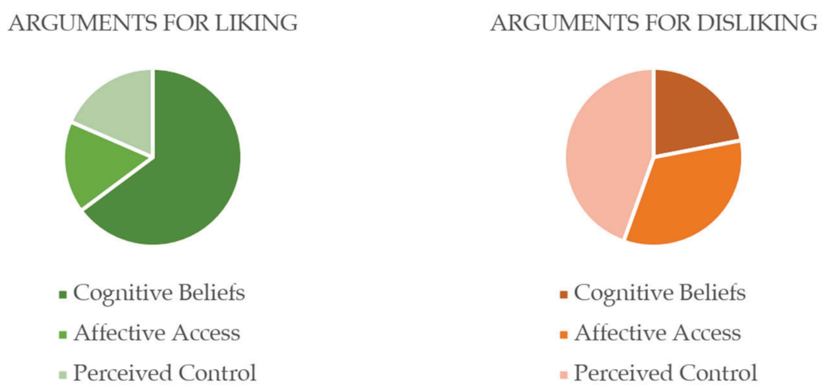

Figure 8. Comparison of argumentation patterns for liking or disliking a teaching topic according to the theory-based attitude dimensions (N = 1278 for liking arguments, N = 788 for disliking arguments).

It is noticeable that the reasons given for the popularity of a topic were predominantly cognitive beliefs (64.8%), followed by a clearly smaller proportion of perceived-control arguments (18.5%), and finally an even smaller proportion of affective-access arguments (16.7%). In contrast, perceived-control arguments (44.5%) dominate the arguments for the unpopularity of teaching topics, followed by a considerable proportion of affective-access arguments (33.5%), while cognitive-beliefs arguments (22.0%) account for only a small proportion.

It is interesting to note that the missing perceived control to teach was dominant in the unpopular topics, although the same argument in a positive sense (perceived control), was not as prominent in the popular ones. Rather, individual convictions about the importance of the subject matter seem to play a role here, which leads teachers to enjoy teaching these subjects. This also reflects the trainee teachers' focus on the child, as it is important to them to have a positive influence on children's development. However, it must also be noted that their understanding of the topics being taught is still limited or naive, as it is often assumed that teaching these topics would automatically lead to children developing a positive, social, environmentally friendly, and sustainable attitude towards them [27].

Finally, the research question "Are there arguments for liking and, respectively, disliking teaching topics that are more pronounced in some teaching topics of Nature–Human–Society than others?" can be answered in the affirmative, although a similar pattern of argumentation could also be found for some teaching topics. Therefore, it is necessary to look at the content of the teaching topics to see which arguments should be weakened or strengthened so that the disliked teaching topics are more acceptable among all trainee teachers.

It should be noted that these assessments always refer to subjective cognitive representations of teaching topics. As these are first-year students, these perceptions were often based on experiences from their own school days or prejudices; after all, their views must first be developed through the practical implementation of teaching such topics. In this respect, these attitudes towards teaching topics cannot yet be regarded as firmly established but as transformable [49], which results in hope and makes the value of teacher training all the more clear. Further studies in the future could examine the attitudes of student teachers at the end of their studies or in their professional lives, whether their likes and dislikes of NMG teaching topics and their responses to the questionnaire are still the same, or whether they have changed.

5. Conclusions

The aim of this study was to show which arguments need to be addressed during the course of study in order to inspire trainee teachers to teach all topics of this multidisciplinary subject. In contrast to other studies and for the first time, the reasons for the popularity and unpopularity of teaching topics were acquired inductively from trainee teachers' points of view. This study provides complementary evidence to support and complete previous conclusions based on quantitative data [22–26]. Therefore, the findings of this study make a significant contribution to higher education and can ultimately have an influence on subsequent teaching practices in the Nature–Human–Society subject.

Since it is well known that those topics in subjects that teachers do not like or do not feel confident in teaching are underrepresented in teaching practices [4,38–40], it is all the more important that teacher trainees at universities are aware of the reasons for these likes and dislikes. In teacher training, they can give trainee teachers a clearer idea of these particular teaching topics in kindergarten and primary school, demonstrating to them that all topics are relevant for living in the world and suitable for illustrative teaching with children. Lastly, this knowledge can give teachers the necessary tools they need to have control over teaching these topics. In this context, it is important to remember what Van-Aalderen and colleagues [6] stated about an evaluation of various teacher training programs aimed at improving teachers' negative attitudes towards science: an approach with "hands-on science activities, inquiry-based teaching methods, cooperative learning (. . .) seems more effective in changing attitude towards science than a content knowledge approach" (p. 711). Therefore, it seems crucial that the course resonates emotionally with the (trainee) teachers and stimulates their interest in the particular situation. As Bulunuz [5] observed, "Experiencing fun, playful, interesting activities in a positive and supportive social environment were important variables for developing preservice science teacher's attitudes toward teaching science" (p. 80). Thus, if we are successful in creating positive and empowering experiences during teacher training, especially in fields that have been previously rejected, we can strengthen their enthusiasm and engagement for teaching those topics in later classroom practice [4,5,26].

In conclusion, the best way to change attitudes is to consider the dimension of their origin. This means that affective-based attitudes are best changed by addressing emotional components, cognitive-based attitudes through strong arguments, and perceived capability through mastering experiences [50,51]. This study has shown where changes have to be made for each topic of the Nature–Human–Society subject. The task in the future is to apply these findings and to form a positive professional attitude among the prospective teachers.

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References

1. Kalcsics, K.; Wilhelm, M. *Lernwelten Natur, Mensch, Gesellschaft—Studienbuch*; Schulverlag Plus: Bern, Switzerland, 2017.
2. Ekelemu, E. Attitude of Teachers, Experience and Background Knowledge Effect on the Use of Inquiry Teaching Method. *Glob. Res. J. Educ.* **2014**, *2*, 198–206.
3. Owusu-Fordjour, C. Attitude of Teachers and its Impact on their Instructional Practice. *Eur. J. Educ. Stud.* **2021**, *8*, 163–176. [CrossRef]
4. Yi-Chun, C.; Hsin-Kai, W.; Ching-Ting, H. Science Teaching in Kindergartens: Factors Associated with Teachers' Self-Efficacy and Outcome Expectations for Integrating Science into Teaching. *Int. J. Sci. Educ.* **2022**, *44*, 1045–1066. [CrossRef]
5. Bulunuz, M. The Role of Playful Science in Developing Positive Attitudes toward Teaching Science in a Science Teacher Preparation Program. *Eurasian J. Educ. Res.* **2015**, *58*, 67–88. [CrossRef]
6. Van Aalderen-Smeets, S.I.; van der Molen, J.H.W. Improving Primary Teachers' Attitudes toward Science by Attitude-Focused Professional Development. *J. Res. Sci. Teach.* **2015**, *52*, 710–734. [CrossRef]
7. Bleicher, R.E. Nurturing Confidence in Preservice Elementary Science Teachers. *J. Sci. Teach. Educ.* **2007**, *18*, 841–860. [CrossRef]
8. Blaseio, B. Sachunterricht in Europa—Fachstrukturen für das geschichtliche, geographische und naturwissenschaftliche Lernen in der Grundschule. *GDSU-J.* **2012**, *12*, 9–25.
9. Erziehungsdirektion des Kantons Bern (Ed.) *Lehrplan 21—Grundlagen*; Gassmann Print: Biel/Bienne, Switzerland, 2016.
10. Erziehungsdirektion des Kantons Bern (Ed.) *Lehrplan 21—Fachbereichslehrplan Natur, Mensch, Gesellschaft*; Gassmann Print: Biel/Bienne, Switzerland, 2016.
11. Breitenmoser, P.; Mathis, C.; Tempelmann, S. Die Ausbildung im Fach NMG an Schweizer Hochschulen: Professionalisierung durch Austausch. In *Natur, MensCH, GesellsCHaft (NMG) Standortbestimmungen zu den Sachunterrichtsdidaktischen Studiengängen der Schweiz*; Breitenmoser, P., Mathis, C., Tempelmann, S., Eds.; Schneider Verlag Hohengehren: Baltmannsweiler, Germany, 2021; pp. 11–16.
12. Adamina, M. Interessen von Schülerinnen und Schülern am Fach und an Themen des Sachunterrichts bzw. des Fachbereichs Natur, Mensch, Gesellschaft (NMG). In *Wie ich mir das denke und vorstelle..." Vorstellungen von Schülerinnen und Schülern zu Lerngegenständen des Sachunterrichts und des Fachbereichs Natur, Mensch, Gesellschaft*; Adamina, M., Kübler, M., Kalcsics, K., Bietenhard, S., Engeli, E., Eds.; Klinkhard: Kempten, Germany, 2018; pp. 311–326.
13. Krapp, A. Die Bedeutung von Interessen für die Lernmotivation und das schulische Lernen—Eine Einführung. In *Schülerinteressen an Themen, Regionen und Arbeitsweisen des Geographieunterrichts*; Hemmer, I., Hemmer, M., Eds.; Hochschulverband für Geographie und seine Didaktik: Weingarten, Germany, 2010; pp. 9–26.
14. Krapp, A. Interesse, Lernen und Leistung. Neue Forschungsansätze in der Pädagogischen Psychologie. *Z. Pädagogik* **1992**, *38*, 747–770. [CrossRef]
15. Silvia, P.J. Curiosity and Motivation. In *The Oxford Handbook of Human Motivation*, 2nd ed.; Ryan, R.M., Ed.; Oxford University Press: New York, NY, USA, 2019.
16. Ryan, R.M.; Deci, E.I. Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being. *Am. Psychol.* **2000**, *55*, 68–78. [CrossRef]
17. Hartinger, A.; Lohrmann, K. Interessen und die Förderung von Interesse im Sachunterricht der Grundschule. In *Schülerinteressen an Themen, Regionen und Arbeitsweisen des Geographieunterrichts*; Hemmer, I., Hemmer, M., Eds.; Hochschulverband für Geographie und seine Didaktik: Weingarten, Germany, 2010; pp. 185–196.
18. Franz, U. *Lehrer- und Unterrichtsvariablen im Naturwissenschaftlichen Sachunterricht. Eine empirische Studie zum Wissenserwerb und zur Interessenentwicklung in der dritten Jahrgangsstufe*; Klinkhardt: Bad Heilbrunn, Germany, 2008.

19. Upmeier zu Belzen, A.; Vogt, H.; Weider, B.; Christen, F. Schulische und außerschulische Einflüsse auf die Entwicklung von naturwissenschaftlichen Interessen bei Grundschulkindern. In *Bildungsqualität von Schule: Schulische und außerschulische Bedingungen mathematischer, naturwissenschaftlicher und überfachlicher Kompetenzen*; Prenzel, M., Doll, J., Eds.; Beltz: Weinheim, Germany, 2002; pp. 291–307.
20. Glauser Abou-Ismail, N.; Pahl, A.; Tschiesner, R. Play-Based Physics Learning in Kindergarten. *Educ. Sci.* **2022**, *12*, 300. [CrossRef]
21. Thoonen, E.E.; Sleegers, P.J.; Peetsma, T.T.; Oort, F.J. Can Teachers Motivate Students to Learn? *Educ. Stud.* **2010**, *37*, 345–360. [CrossRef]
22. Pahl, A. Teaching Physics in Kindergarten and Primary School: What do Trainee Teachers Think of This? In *Physics Teacher Education. What Matters?* Borg Marks, J., Galea, P., Gatt, S., Sands, D., Eds.; Springer: Basel, Switzerland, 2022; pp. 59–73. [CrossRef]
23. Tschiesner, R.; Pahl, A. Trainee Teachers' Preferences in the Subject 'Human-Nature-Society': The Role of Knowledge. *ICERI Proc.* **2019**, *12*, 3167–3176. [CrossRef]
24. Tschiesner, R.; Pahl, A. The Big Five and Teaching Preferences in Nature-Human-Society. *Edulearn Conf. Proc.* **2022**, *14*, 6578–6586. [CrossRef]
25. Pahl, A.; Tschiesner, R. What Influences Attitudes and Confidence in Teaching Physics and Technology Topics? An Investigation in Kindergarten and Primary-School Trainee Teachers. *Sustainability* **2022**, *14*, 87. [CrossRef]
26. Pahl, A.; Tschiesner, R. Vocational Interests and Teaching Preferences: Who Prefers Which Teaching Topic in the Nature–Human–Society Subject? *Behav. Sci.* **2023**, *13*, 658. [CrossRef]
27. Kalcsics, K.; Moser, A.S.; Stirnimann, A. Es ist sehr wichtig, dass die Schülerinnen und Schüler sich selbst kennen lernen—Die Auswahl von Sachunterrichtsthemen durch Studierende. In *Sachunterricht—Zwischen Kompetenzorientierung, Persönlichkeitsentwicklung, Lebenswelt und Fachbezug*; Giest, H., Goll, T., Hartinger, A., Eds.; Klinkhardt: Bad Heilbrunn, Germany, 2016; pp. 124–131.
28. Dunlop, L.; Rushton, E.A.C.; Atkinson, L.; Ayre, J.; Bullivant, A.; Essex, J.; Price, L.; Smith, A.; Summer, M.; Stubbs, J.E.; et al. Teacher and Youth Priorities for Education for Environmental Sustainability: A Co-Created Manifesto. *Br. Educ. Res. J.* **2022**, *48*, 952–973. [CrossRef]
29. Eagly, A.; Chaiken, S. *The Psychology of Attitudes*; Wadsworth Group/Thomson Learning: Belmont, CA, USA, 1993.
30. Van Aalderen-Smeets, S.; van der Molen, J.W.; Asma, L.J.F. Primary Teacher's Attitudes Toward Science: A New Theoretical Framework. *Sci. Educ.* **2012**, *35*, 577–600. [CrossRef]
31. Mayring, P. *Einführung in die qualitative Sozialforschung: Eine Anleitung zu qualitativem Denken*, 5th ed.; Beltz Verlag: Weinheim, Deutschland, 2002.
32. PHBern. Studierendenstatistik. Available online: https://www.phbern.ch/ueber-die-phbern/hochschule/portraet/statistiken/statistik-studierendenstatistik (accessed on 5 April 2024).
33. Müller, H.; Adamina, M. *Lernwelten Natur-Mensch-Mitwelt—Grundlagenband*; Schulverlag Plus: Bern, Switzerland, 2008.
34. Pahl, A.; Tschiesner, R.; Adamina, M. The 'Nature-Human-Society'—Questionnaire: Psychometric Properties and Validation. *ICERI2019 Proc.* **2019**, *12*, 3196–3205. [CrossRef]
35. Bühner, M. *Einführung in die Test-und Fragebogenkonstruktion*, 2nd ed.; Pearson: München, Germany, 2011.
36. Bortz, J.; Schuster, C. *Statistik für Human- und Sozialwissenschaftler*, 7th ed.; Springer: Berlin/Heidelberg, Germany, 2010.
37. Döring, N. *Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften*, 6th ed.; Springer Nature: Berlin, Germany, 2023.
38. Pendergast, E.; Lieberman-Betz, R.G.; Vail, C.O. Attitudes and Beliefs of Prekindergarten Teachers Toward Teaching Science to Young Children. *Early Child. Educ. J.* **2017**, *45*, 43–52. [CrossRef]
39. Schiefele, U.; Schaffner, E. Teacher Interests, Mastery Goals, and Self-Efficacy as Predictors of Instructional Practices and Student Motivation. *ScienceDirect* **2015**, *42*, 159–171. [CrossRef]
40. Adamina, M.; Labudde, P.; Gingins, F.; Nidegger, C.; Bazzigher, L.; Bringold, B.; Zeyer, A. *HarmoS Naturwissenschaften+. Kompetenzmodell und Vorschläge für Basisstandards Naturwissenschaften. Wissenschaftlicher Schlussbericht*; Suterprint: Ostermundigen, Switzerland, 2009.
41. Baumert, J.; Kunter, M. Das Kompetenzmodell von COACTIV. In *Professionelle Kompetenzen von Lehrkräften. Ergebnisse des Forschungsprogramms COACTIV*; Kunter, M., Baumert, J., Blum, W., Klusmann, U., Krauss, S., Neubrand, M., Eds.; Waxmann: Münster, Germany, 2011; pp. 29–53.
42. Bergmann, C.; Eder, F. *Allgemeiner Interessen-Struktur-Test mit Umwelt-Struktur-Test (UST-R)*; Revision; Hogrefe: Göttingen, Germany, 2005.
43. Rauh, T. "Die Beziehung Zwischen den Menschen und der Sonne Verändert Sich", Pressemitteilung Experimenta, das Science Center. Available online: https://www.experimenta.science/wp-content/uploads/2023/05/20230530_Interview-mit-Harry-Cliff.pdf (accessed on 5 May 2024).
44. Magai, C.; McFadden, S.H. *The Role of Emotions in Social and Personality Development: History, Theory, and Research*; Springer US: New York, NY, USA, 1995.
45. Krapp, A. Das Interessenskonstrukt. Bestimmungsmerkmale der Interessenshandlung und des individuellen Interesses aus Sicht einer Person-Gegenstands-Konzeption. In *Interesse, Lernen, Leistung. Neuere Ansätze der pädagogisch-psychologischen Interessensforschung*; Krapp, A., Prenzel, M., Eds.; Verlag Aschendorff: Münster, Germany, 1992; pp. 297–329.

46. Osborne, J.; Shirley, S.; Collins, S. Attitudes towards Science: A Review of the Literature and its Implications. *Int. J. Sci. Educ.* **2003**, *25*, 1049–1079. [CrossRef]
47. Bandura, A. Self-efficacy: Toward a Unifying Theory of Behavioral Change. *Psychol. Rev.* **1977**, *84*, 191–215. [CrossRef] [PubMed]
48. Kapucu, S. Identification of the Physics Subjects that Are Liked/Disliked and Why these Subjects Are Liked/Disliked by Student Teachers. *J. Theory Pract. Educ.* **2016**, *12*, 827–843.
49. Glasman, L.R.; Albarracín, D. Forming Attitudes that Predict Future Behavior: A Meta-Analysis of the Attitude-Behavior Relation. *Psychol. Bull.* **2006**, *132*, 778–822. [CrossRef] [PubMed]
50. Werth, L.; Denzler, M.; Mayer, J. *Sozialpsychologie—Das Individuum im sozialen Kontext. Wahrnehmen—Denken—Fühlen*, 2nd ed.; Springer: Berlin, Germany, 2020.
51. Fabrigar, L.R.; Petty, R.E. The Role of the Affective and Cognitive Bases of Attitudes in Susceptibility to Affectively and Cognitively Based Persuasion. *Pers. Soc. Psychol. Bull.* **1999**, *25*, 363–381. [CrossRef]

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Review

How Do Nature-Based Outdoor Learning Environments Affect Preschoolers' STEAM Concept Formation? A Scoping Review

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Abstract: This scoping review examined the impact of nature-based outdoor learning environments on the formation of STEAM (science, technology, engineering, arts, and mathematics) concepts in preschoolers. Preschool age (3–5 years) is the time when physical interaction with surrounding built environments increases, and spontaneous learning from the environment intensifies—making it an ideal age range to promote nature-based informal learning. An outdoor learning environment can influence STEAM concept formations of preschoolers with an intentional design that offers STEAM learning affordances. Despite the rising interest in early STEAM education, there is still limited literature on how the outdoor environment may influence STEAM learning behaviors of preschoolers (3–5 years old). This scoping review intended to evaluate the existing knowledge regarding the physical factors contributing to STEAM learning affordances in an outdoor environment for children aged three to five. The review included studies from the last twenty years. This scoping review was conducted following the criteria outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR). For this scoping review, 843 citations were discovered across four databases (JSTOR, Scopus, EBSCOhost, and Web of Science), ProQuest, and Google Scholar, and 31 articles were considered eligible for inclusion. The paper synthesized those 31 studies to identify the key STEAM learning behaviors of children and STEAM-activity-supportive settings that may positively influence preschoolers' STEAM concept development.

Keywords: preschooler; STEAM concept; landscape elements; informal learning; affordances

1. Introduction

Understanding the impact of nature-based outdoor learning environments on the formation of STEAM (science, technology, engineering, arts, and mathematics) concepts in preschoolers is essential for many reasons. Early childhood is a critical period for cognitive and social development, and experiences during this time can shape future learning and interest in STEAM disciplines. Nature-based environments, as a source of diverse opportunities for experiential learning, can promote children's curiosity, problem-solving, and creativity through direct interaction with natural elements [1]. There are endless possibilities for reimagining childcare 'playgrounds' as nature-based outdoor informal STEM learning environments in 188,000 licensed and family childcare facilities in the U.S., where more than 13 million [2] children aged zero to five spend the majority of their waking hours every day. Nature, being a constant source of varied environmental learning opportunities, has gained a wide range of attention in early childhood education, but there are no established guidelines on measuring and enhancing 'nature' in early outdoor environments with low-cost interventions or curriculum guidance/courses/certificates to promote nature-based informal early STEAM learning. STEAM is linked with developing early interests in science, technology, engineering, and math, which can lead to future interests and address the growing concern that the U.S. is falling behind in STEAM (ranked 13th in mathematics and 31st in science [3] test scores internationally and with more than 1 million STEM jobs unfilled). A scoping review of the current empirical research on the impact of nature-based learning environments on early STEAM concept formation in preschoolers may guide preliminary understanding and insights regarding this critical aspect of early childhood education tied to national interests.

The Experiential Learning Theory (ELT), as explained by Armstrong and Fukami [4], emphasizes the importance of direct experiences in early childhood learning. This theory views learning as a dynamic process that integrates children's ideas, their ability to experiment and refine concepts, and the construction of new knowledge. It highlights the continuous interaction and adaptation between children and their environments where thoughts, feelings, experiences, culture, physical sensations, emotions, inquiry, and reflection are constantly in flux, influencing and reshaping everyday learning [5]. Furthermore, other researchers [6] support that firsthand experiences with nature allow children to observe the complex interdependencies within ecosystems. Such direct, hands-on experiences are more impactful than simulated ones, as they allow children to fully engage with their senses and interact directly with the natural world. In children's direct interaction with their surroundings, items like play equipment, [7] trees, plants, various landscape features, and water can impact their behavior. Also, the topography and the paths that link these elements to the children's homes emphasize the importance of these small-scale environmental aspects in a child's interaction with their environment [8].

Measuring the quality of the cognitive development of young children is more difficult than older ones because young children experience vast variations in the different personal, developmental, and environmental factors affecting their behaviors [9]. The educational quality is determined not only by the educators (who) and the curriculum (what) but also by the physical setting (where) of the educational service. This environmental aspect of learning is now acknowledged as a key factor in delivering high-quality early childhood education and care [10,11]. The importance of the physical environment in early childhood education was first emphasized by Loris Malaguzzi, the founder of the Reggio Emilia approach, who described it as the "third teacher". He suggested that, in addition to family and educators, the design and organization of educational spaces are crucial in shaping early childhood developmental trajectories [12]. In this paper, we emphasized environmental "affordances" as a key concept in understanding STEAM learning environments. While constraints refer to what may be lacking in a child's environment, affordances refer to the possibilities that the environment offers or affords to children/learners in the shape of learning opportunities. It does not mean what the child is learning or doing, but only whether the possibility exists [13]. An environment with an abundance of diverse affordances for exploration and discovery is essential for maximizing children's learning capacity, behaviors, and attitudes [14]. Research indicates that outdoor environments significantly enhance children's symbolic play more than indoor environments due to their natural materials, open-endedness, and spaciousness. The complexity and richness of natural environments offer a level of stimulation that cannot be replicated indoors [15]. Although outdoor play was relatively less researched in the latter decades of the twentieth century, many studies [16] emphasized the critical role of outdoor play spaces and provided insights into spatial organization, showing how spatial design can be a powerful tool in education and enhance the overall quality of children's daily experiences.

According to the author of the book *Spaces for Children* [14], children typically interact with their physical surroundings in a straightforward and observable manner. For infants, who find joy in exploring and moving, and preschoolers, who are focused on mastering muscle skills, their immediate environment serves as the primary source of learning motivation. However, the impact of the physical context, particularly the built environment, has often been overlooked. Recent studies aim to challenge this perspective, arguing that while the built environment may not be a primary factor in child development, it can significantly affect the developmental process, especially for young children who have little control over their surroundings and may be more engaged with the physical than the social environment [14]. Before formal education shapes their learning, young children naturally seek to understand the world through observation, investigation, and social interaction, particularly in informal environments like childcare playgrounds, museums, and parks. While this self-driven learning is valuable, it is not sufficient on its own. Structured educational settings (physical environment) and deliberate teaching are crucial in children's learning. To effectively shape these environments, it is important to integrate an understanding of children's learning processes with clear objectives and content for science education [17]. Children's initial understanding develops from limited experiences, necessitating exposure to formal and informal learning environments. While traditional educational tools like demonstrations and textbooks are valuable, they cannot replace the hands-on experiences crucial for deep learning. Without these, children might grasp facts and excel in tests but will be at risk of viewing science as a rigid, disconnected set of instructions, undermining their confidence in experimentation, and fostering a belief that science is an elusive realm, understood only through external authority rather than personal exploration and understanding [17].

Young children actively engage with their environment to develop a fundamental understanding of the phenomena they are observing and experiencing [18]. Children form their own theories to make sense of everyday experiences, which assists them in embracing a more scientific perspective of their world. Cognitive research reveals that children's explorations are rooted in tangible contexts, utilizing their senses to observe, investigate, and draw conclusions from the world around them. This natural curiosity leads them to constantly ask questions and seek understanding, not in an idealized or laboratory setting but within the complexities of their everyday lives [17]. The saying "I hear, and I forget. I see, and I remember. I do, and I understand" suggests that children learn most effectively through hands-on experiences. This approach aligns with children's natural curiosity and capacity for self-discovery, marking their initial engagement with science [19]. Engaging in scientific activities helps young children appreciate and understand their environment and develop key scientific skills. These skills include curiosity, questioning, investigation, discussion, reflection, and forming ideas and theories [19,20]. STEM (science, technology, engineering, and mathematics) opportunities in early childhood take learning to the next level by adding affordances related to math, engineering, and technology. Every child deserves STEM learning environments that are wondrous, stimulating, and innovative, and that value their astonishments, curiosities, questions, and observations [21]. Exploring the natural world is a core element of childhood, making science/STEM a natural fit in early education. The increasing awareness of children's early cognitive abilities and eagerness to understand the natural world makes a compelling case for early childhood environments that offer rich and challenging opportunities for STEM learning. As Worth [22] noted, children's inquiry into natural phenomena lays the groundwork for science learning and appreciation of nature and serves as a valuable context for developing learning approaches, practicing basic literacy and math skills, and learning collaboration [23].

How can we provide children with the best possible learning environment during their preschool years? To answer this question, recent research in early childhood science education and outdoor learning environments has attracted renewed attention to improving outdoor environment quality through design. However, very few studies have discussed how the nature-based outdoor learning landscape influences the STEM concept formation of children and which physical factors of an outdoor landscape impact childhood learning. This scoping review focuses on STEAM, which integrates the 'arts' with STEM, expanding the acronym to include the "A". By including disciplines such as arts, music, literature, and dance, this inclusion expands to a comprehensive early learning philosophy that not only boosts children's technical proficiency but also cultivates their creative aptitude. According to a plethora of research, how children informally learn, especially through play, is influenced by nature, architecture, and policies that govern how school grounds are used [20]. Physical factors of a natural outdoor learning landscape can prompt early childhood STEAM learning.

The domains of this scoping review encompass "affordances of outdoor learning environment for early childhood" and "outdoor learning landscape design elements" in relation to "STEAM/STEM/Science learning activities and behaviors of children"(Figure 1).

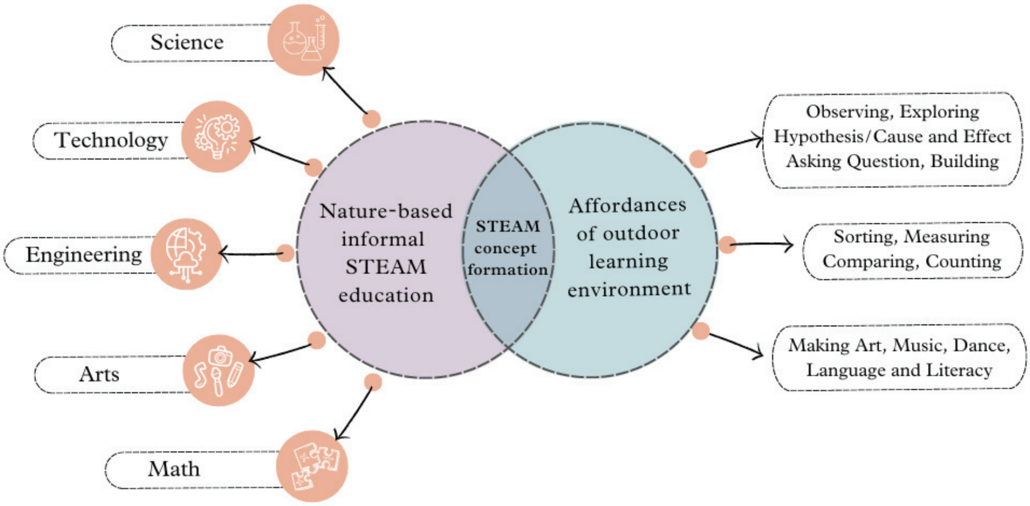

Figure 1. Study domains of reviewed resources.

A significant characteristic of outdoor play and learning is the relative independence of the child to explore and experiment. Compared to indoor formal learning and even indoor play, there are typically fewer restrictions and more freedom in outdoor times—and hence, greater opportunities for children to explore, experiment, solve problems of interest, and venture into activities that they enjoy when adults are not overseeing (messy, risk-taking, etc.). So, there is an interesting negotiation between the benefits of playing freely outdoors, which leads to discoveries, and the role of adults in curating children's STEAM concept formation. This scoping review is an approach to setting a bridge between these domains.

2. Research Method

This scoping review was conducted in accordance with the criteria outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR), using Arksey and O'Malley's (2005) methodological framework [24], as seen in Figure 2. The methodology encompassed the subsequent stages: (1) identification of research questions, (2) identification of relevant studies, (3) selection of relevant studies, (4) data charting, and (5) collating, summarizing, and reporting the results.

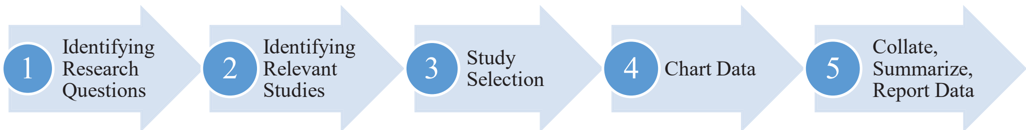

Figure 2. Methodological framework (Arksey and O'Malley, 2005) [24].

2.1. *Identification of the Research Questions*

Due to its intricate characteristics, the concept of nature-based STEAM education for preschoolers has not yet been extensively investigated. Therefore, the research question that guided the investigation in this scoping review was: what empirical knowledge is available from the existing literature regarding the impact of nature-based outdoor learning landscape on preschoolers' STEAM learning? The foundational research questions derived from the research objectives established within the PCC (population, concept, and context) framework [25] are presented in Table 1.

Table 1. Research questions based on PCC (population/concept/context).

	Research Question	Specific Objective
(1)	Based on the discussion of the existing literature, which types of interaction with natural elements and materials (CX *) in outdoor environments enhance STEAM learning and curiosity (CP *) among preschoolers (P *)?	Exploring different types of STEAM-related behaviors exhibited by children while interacting with the outdoor environment, such as questioning, exploring, building, or using STEAM-related language.
(2)	From the existing research, which characteristics of a nature-based outdoor learning landscape (CX) were identified that support STEAM learning opportunities (CP) for preschoolers(P)?	Documenting the specific areas within the natural outdoor environment where STEAM learning behaviors occur and the context of these interactions. Also, the frequency of children's engagement with different landscape elements in the natural outdoor environment (e.g., plants, water, and wildlife) could lead to STEAM learning opportunities.
(3)	In the existing literature, what were teachers'/caregivers' (P) perceptions regarding the benefits and challenges of integrating (CP) nature-based outdoor STEAM learning into the preschool (P) curriculum across diverse environmental settings (CX)?	Gathering insights from educators on the perceived affordances of the natural outdoor environment for informal STEAM learning and on children's STEAM learning behaviors.

* CX = context, CP = concept, and P = population.

2.2. Identification of Relevant Studies

Database Search. Three sets of search terms were used in four selected databases: JSTOR, Scopus, EBSCOhost, and Web of Science. The title of this research was used to search for relevant studies on ProQuest Central. The search terms were carefully crafted by looking at the titles, abstracts, and keywords of papers already selected as relevant. The Boolean operator "OR" was used to segregate the search phrases inside each set, and the operator "AND" was used to join the different sets. The search terms are shown in Table 2 below.

Table 2. Search keywords.

Population: Preschoolers	Search terms: Early child * OR preschool * OR kid OR kindergarten OR pre-K OR 3–5 years OR young child *
Concept: STEAM/STEM/Science Learning	Search terms: STEM OR STEAM OR Science OR Education OR Learn * OR Science OR Technology OR Engineering OR Art * OR Math *
Context: Nature-based Outdoor Learning Landscape	Search terms: Outdoor OR Natur * OR Landscape OR Playscap * OR Childcare OR Daycare OR Playground OR Playspac *

Note: the asterisk "*" is a truncation symbol that directs the search engine to find all forms of a given word.

Grey Literature Search. Recent advancements in preschool science and mathematics education have attracted renewed interest from researchers who are invested in pre-kindergarten education. Consequently, numerous independent research groups and educational institutions are engaged in outdoor STEAM learning and teaching activities and disseminate their findings. Incorporating non-commercially published material, also known as "grey literature", in evidence reviews reduces publication bias and offers a more comprehensive and unbiased representation of the evidence [26]. This scoping review applied three approaches to locate grey literature that is relevant to this review: (1) a Google Scholar search using the title of this research to identify relevant studies; (2) searching known databases (e.g., www.childrenandnature.org (accessed on 23 May 2024), www.childhoodbynature.com (accessed on 23 May 2024), www.greenschoolyards.org (accessed on 23 May 2024), and www.texaschildreninnature.org (accessed on 23 May 2024)); and (3) searching websites explicitly focused on outdoor learning initiatives (e.g., Natural Learning Initiative website:

www.naturalearning.org (accessed on 23 May 2024)), and early childhood learning (e.g., "Science Preschool: ECLKC-Head Start"—https://eclkc.ohs.acf.hhs.gov/school-readiness/article/science-preschool (accessed on 23 May 2024)). The inclusion process prioritized peer-reviewed papers over grey literature if both sources provided identical information.

2.3. Study Selection

The search looked for journal articles published between 2004 and 2023 (20 years). Over the past 20 years, scientific research on nature-based early childhood education has shifted from perception-based to evidence-based. Initially driven by anecdotal observations and beliefs about the benefits of outdoor play, recent studies have provided robust empirical support for these practices. Research now highlights measurable improvements in cognitive development, emotional regulation, and physical health among children engaged in nature-based education. Advanced methodologies, such as longitudinal studies and randomized controlled trials, have validated these findings, leading to broader acceptance and integration of nature-based approaches in early childhood curricula. This transformation underscores the importance of empirical evidence in shaping educational practices and policies. Although it is practically impossible to pinpoint a particular year as the starting point of this paradigm shift, we believe the past 20 years is a significant timeframe to capture the critical resources for addressing the scope of this paper. Study inclusion criteria are provided in Table 3. Each title and abstract were read to screen the 843 citation records, based on the following inclusion and exclusion criteria, to decide to finalize related studies:

Table 3. Inclusion and exclusion criteria.

	Inclusion Criterion	Exclusion Criterion
1.	Articles published from 2004 to 2023	Full text not attained
2.	English language	Not related to learning/education
3.	Focus on preschoolers/ 3 to 5 years old	Study with toddlers/school-going children
4.	Focus on outdoor STEAM/STEM/ science Learning	STEAM/STEM/science learning inside the classroom
5.	Focus on outdoor play and learning environment	Studies about outdoor play and health/physical activity/restoration/social interaction/ differently able children.

2.4. Charting of Data

The final Microsoft Excel-based data charting form was developed to extract the following study attributes: Data Source, Reference Type, Publication Outlet, Study Topic, Publication Year, Research Type, Data Collection Methods, Study Location/Region, Facilitator, Children Age Range, Landscape Elements, STEM/STEAM/Science Learning Behavior, and STEAM-activity-supportive setting. Table 4 below represents the initial coding categories.

Table 4. Selected initial coding categories.

Code	Description of the Code	Example
Data Source	Source of the selected reviewed Journal Articles/Books/Book Chapters	JSTOR, Scopus, EBSCOhost, ProQuest Central, etc.
Reference Type	Type of review material recorded	Journal Articles/Books/ Book Chapters

Table 4. *Cont.*

Code	Description of the Code	Example
Publication Outlet	Journal/Book in which the study was published	Redleaf Press/ Science and Children
Study Topic	The focus areas discussed in each selected record	Nature-based Outdoor/STEAM Learning
Publication Year	The year in which the study was published	2017, 2015
Research Type	Type of research conducted based on method and data	Qualitative Research, Case-Study Research
Data Collection Methods	Type of methods used for collecting data from the study site	Behavior Mapping, Interview
Study Location/ Region	Name of the country where the study was conducted	USA/Australia
Participant/ Beneficiary of the Study	Description of who participated or benefited from the study	Teacher/Children
Children Age Range	Description of the age of the children	3–5 years
Landscape Elements	Available landscape elements present during research	Trails, Garden, Wooden deck
STEM/STEAM/ Science Learning Behavior	Behavior of children, identified during outdoor play, which is relevant to STEAM learning	Art Building Exploring
STEAM Activity-Supportive Setting.	Outdoor settings that support and enhance STEAM-related activity	Sand Play Area, Garden

3. Reporting the Results

After searching, a total of 843 (n = 843) resources (JSTOR: 286, Scopus: 197, EBSCOhost: 235, Web of Science: 96, and ProQuest Central and Google Scholar: 29) were identified. The total number of books and articles resulted in 814 from all databases except ProQuest Central and Google Scholar. A total of 198 records were screened by reading the heading and abstract, and after a relevancy check, 87 journal articles were excluded. The majority were excluded due to the focus on early childhood STEAM education within classroom environments; they were not nature-based outdoor environments and they were not preschoolers (3- to 5-year-old children). An additional 29 records were obtained through a combination of manual reference list searching, ProQuest Central, and Google Scholar searches for grey literature using the research's initial title. After a full body review of all 140 papers, 109 were removed according to eligibility criteria, and 31 were finally included in the scoping review. Figure 3 below represents the (PRISMA 2020) flow diagram showing literature and study selections.

The final scoping review included 19 journal articles, eight book chapters, and four books. Most of the study was focused on STEAM learning and nature-based outdoor environments. Few discussed the affordances of the outdoor learning environment. Although outdoor play and learning are common in all studies, play-focused studies were limited in this review (Figure 4).

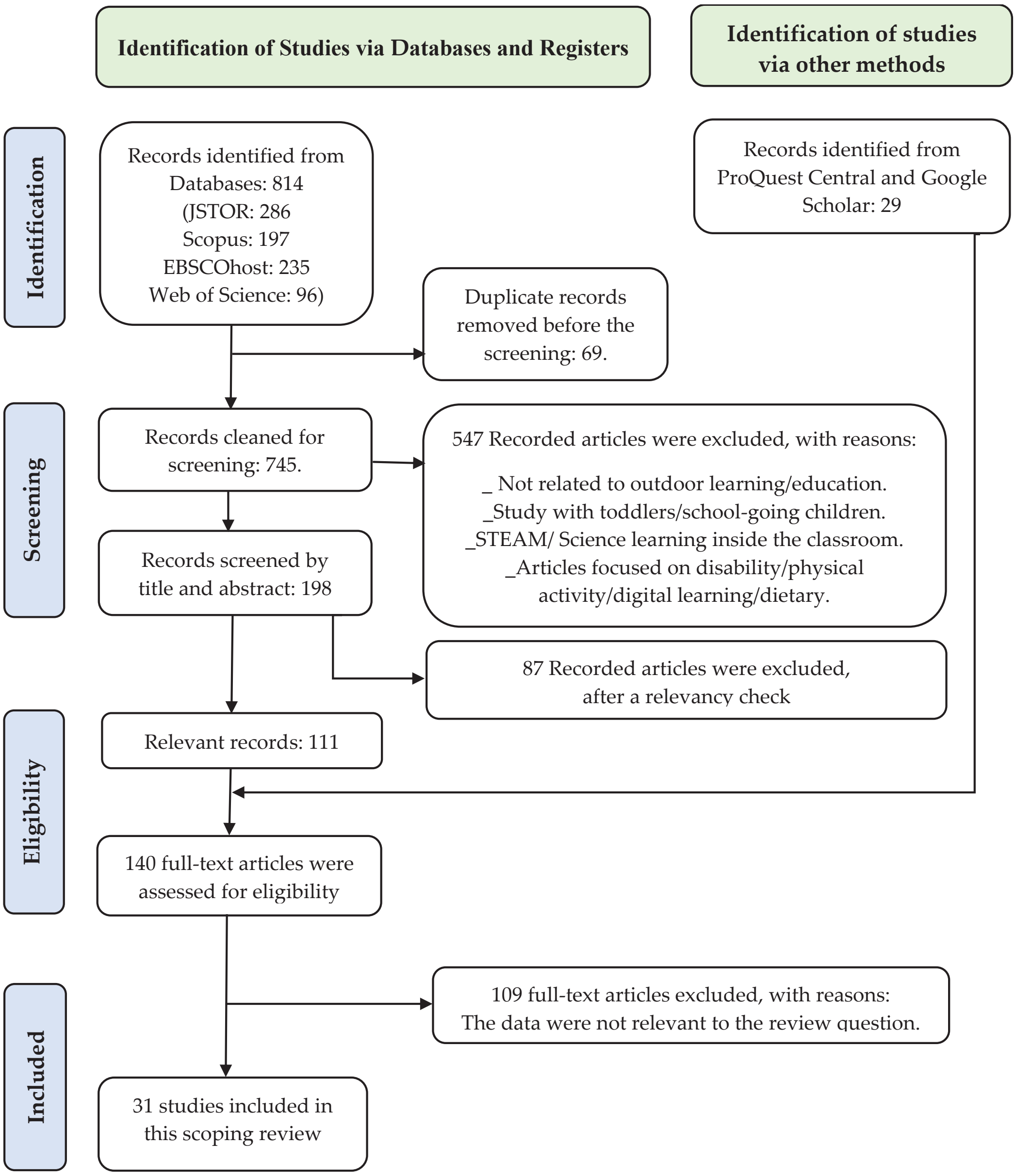

Figure 3. PRISMA 2020 flow diagram showing literature and study selection.

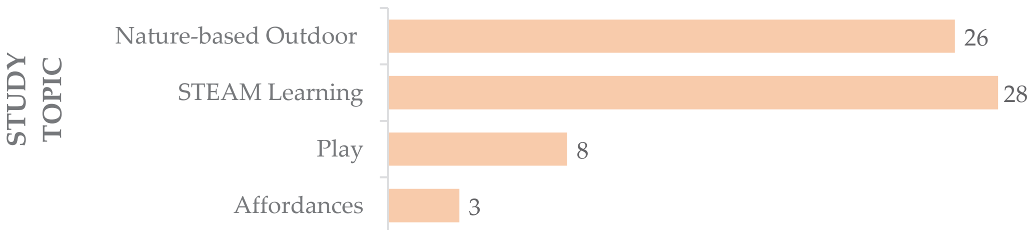

Figure 4. Study topic of reviewed studies.

3.1. Study Characteristics of the Reviewed Studies

Although search criteria show the timespan from 2004 to 2023, relevant documents included in the records were published from 2006. A growth trend is evident in the graph starting from 2016, whereas the quantity of published documents has multiplied from the preceding twelve years. Among the published papers after 2004, ten papers (32%) were published between 2006 and 2015 (10 years), ten papers (32%) were published in the time span of 2016 to 2019 (4 years), where eleven papers (36%) published in the most recent four years of 2020–2023, which is quite consistent. The time distribution indicates that the convergence of early childhood science/STEM/STEAM education and outdoor learning has only recently occurred, and there is a surge in attention toward this intersection of those two fields. (Figure 5 represents the study characteristics summary.)

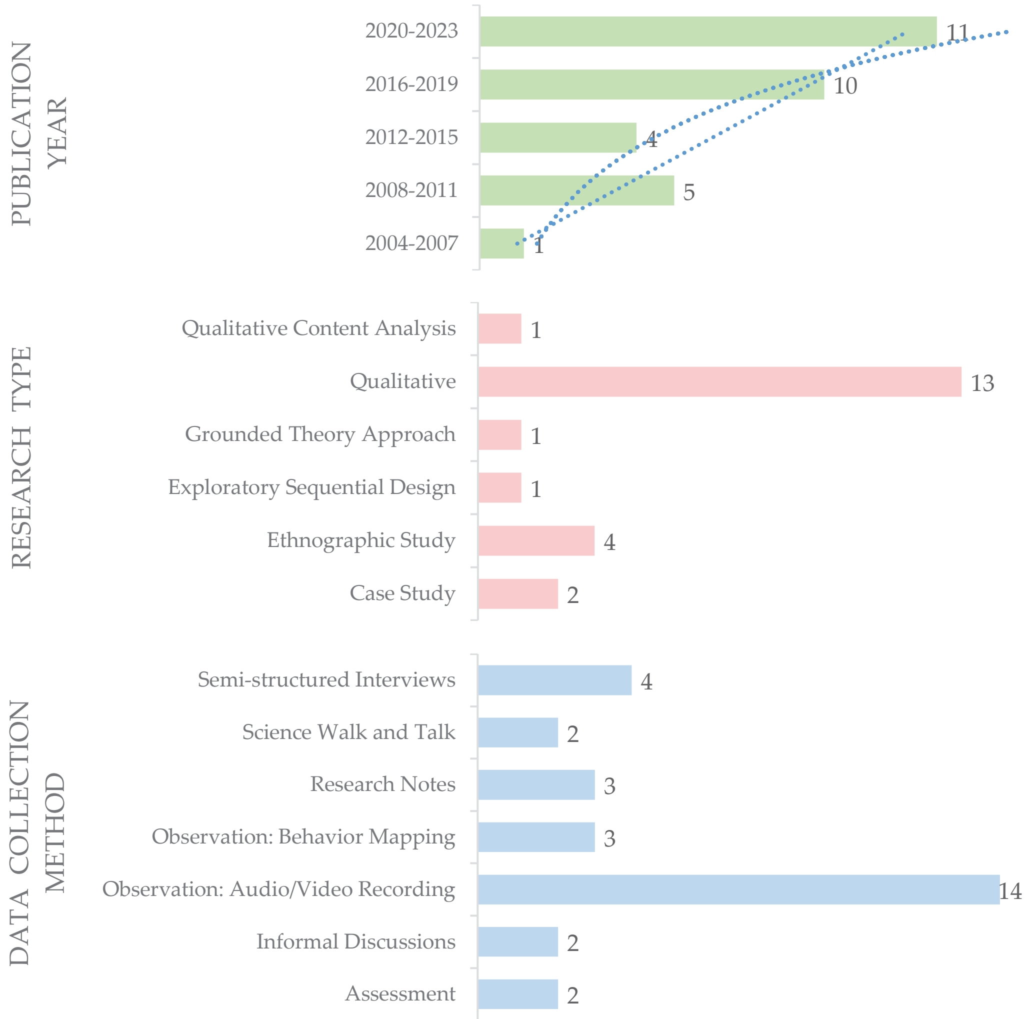

Figure 5. Study characteristics of the reviewed studies.

The qualitative approach was the most common type of research method for the selected papers (13 studies). Campbell and Speldewinde [7,27–29] conducted their four studies using a comparable methodology. These authors participated in ethnographies for one to five years of recurrent visits to Bush Kinder (preschool outdoor learning programs in Australia). Following the diverse array of data collection methods typically employed by ethnographies, they also utilized field notes, semi-structured interviews, and image recording. Miller, A. R. and Saenz, L. P. [30] published one of the three mixed-method research studies using exploratory sequential design, and Kiewra, C. and Veselack, E. [31] published case study research using observational data and teachers' nature notes as data collection methods.

In terms of geographical distribution, as presented in Figure 6, the reviewed studies were conducted in Italy: 1, Germany: 1, New Zealand: 1, Norway: 1, Sweden: 1, Australia: 5, and USA: 12. In addition to these, another 10 studies, comprising books and book chapters, examined the topic of STEAM and outdoor learning environment in a broad manner that is relevant to children worldwide. These additional studies included in this scoping review were mainly carried out in the United States and Australia. In general, all of the studies were conducted in developed countries.

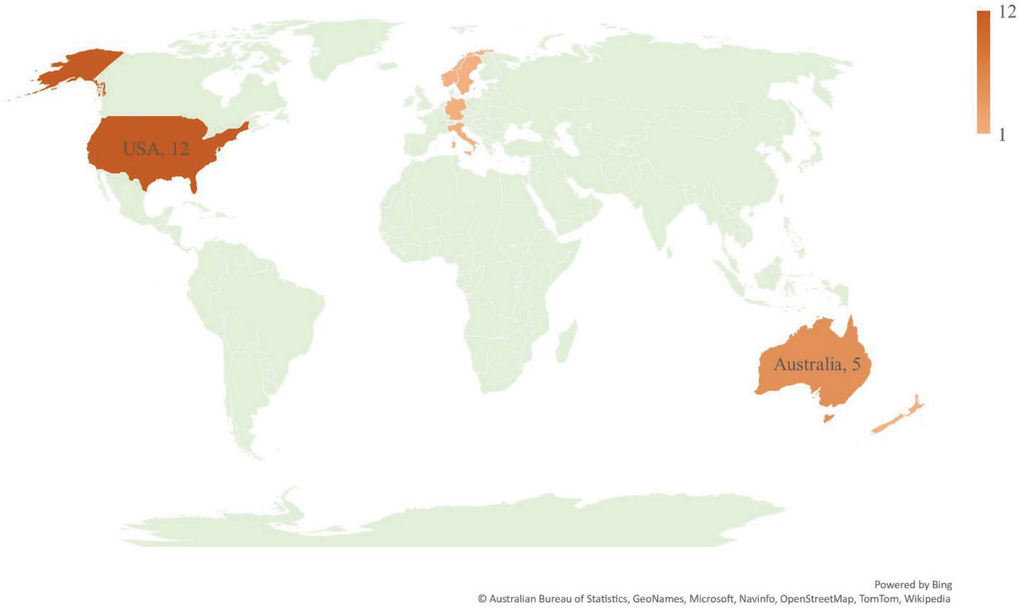

Figure 6. Study location/region.

3.2. Program Characteristics of the Reviewed Studies

Considering exclusively the reviewed articles that focus on preschoolers (3–5), this review also included a few studies with the age group of Infant/Toddler (0–2) and Primary/Elementary (4–11). Whenever research encompassed "children" as a general term, they were counted as Early Childhood (EC). A total of 28 studies of this review group included information about the participant or beneficiary of the study. Although different groups of people participated and benefited from the studies, children were the major participants in overall studies. The largest proportion of studies (18 studies, 64%) were children-led. Eight studies (29%) present both children and teachers as the facilitators, while only one study addressed other related groups, such as administrators and parents. Table 5 and Figure 7 illustrate the publication and program characteristics of the reviewed studies, respectively.

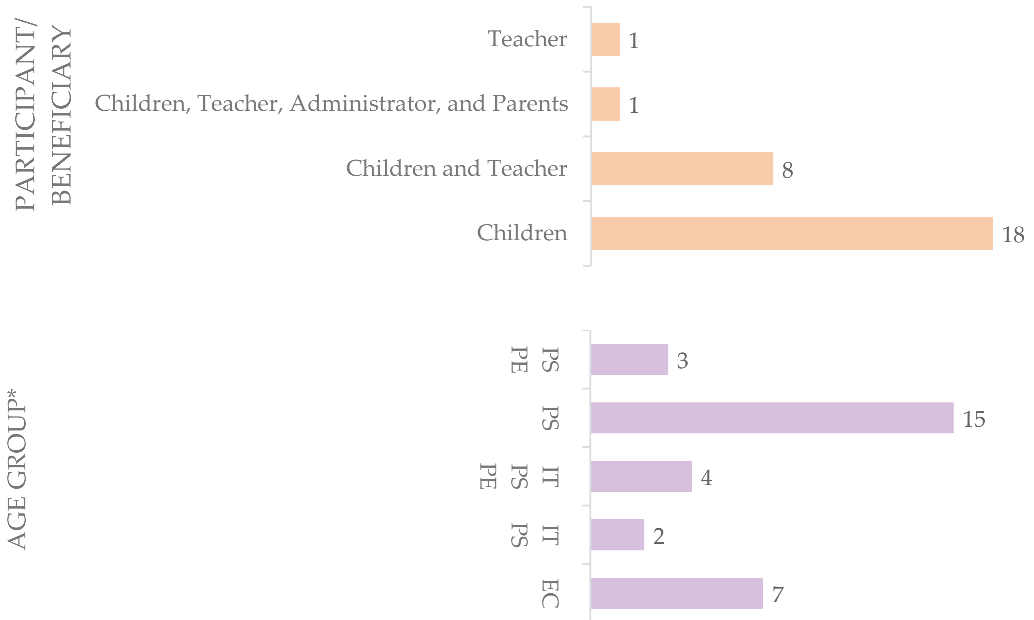

Figure 7. Program characteristics of the reviewed studies. * (Infant/Toddler (0–2) = IT | Pre-School (3–5) = PS | Primary/Elementary (4–11) = PE | Early Childhood = EC).

Table 5. Publication characteristics of the reviewed studies.

No.	Year	Authors	Study Title	Publication Outlet	Type	Data Source	ID
1	2023	Speldewinde, C, and Campbell, C.	Bush kinders: developing early years learners' technology and engineering understandings	*International Journal of Technology and Design Education*	JA	WOS	[7]
2	2023	Speldewinde, C., and Campbell, C.	Bush kinders: enabling girls' STEM identities in early childhood	*Journal of Adventure Education and Outdoor Learning*	JA	WOS	[27]
3	2022	Campbell, C. and Speldewinde, C.	Bush Kinders in Australia: A Creative Place for Outdoor STEM Learning	*Children's creative inquiry in STEM*	BC	GS	[28]
4	2022	Weiser, L. E.	Young Children's Free Play in Nature: An Essential Foundation for STEM Learning in Germany	*Play and STEM Education in the Early Years: International Policies and Practices*	BC	SCP	[32]
5	2022	Worch, E., Odell, M., and Magdich, M.	Engaging Children in Science Learning Through Outdoor Play	*Play and STEM Education in the Early Years: International Policies and Practices*	BC	SCP	[33]
6	2021	Bartolini, V. C.	Creating a Reggio-inspired STEM Environment for Young Children	*Creating a Reggio-inspired STEM Environment for Young Children*	BK	EH	[21]
7	2021	Skalstad, I. and Munkebye, E.	Young children's questions about science topics when situated in a natural outdoor environment: a qualitative study from kindergarten and primary school	*International Journal of Science Education*	JA	EH	[34]
8	2021	Miller, A. R. and Saenz, L. P.	Exploring relationships between playspaces, pedagogy, and preschoolers' play-based science and engineering practices	*Journal of Childhood, Education & Society*	JA	SCP	[30]
9	2020	Campbell, C. and Speldewinde, C.	Affordances for Science learning in "Bush kinders"	*International Journal of Innovation in Science and Mathematics Education*	JA	SCP	[29]
10	2020	Tunnicliffe, S. D.	Emerging biology in the early years: How young children learn about the living world	*Emerging Biology in the Early Years: How young children learn about the living world*	BK	PQ	[35]
11	2020	Krogh, S. L. and Morehouse, P.	The Early Childhood Curriculum: Inquiry Learning Through Integration	*The early childhood curriculum: Inquiry learning through integration*	BK	PQ	[36]
12	2019	Lee, C. K. and Ensel Bailie, P.	Nature-based education: using nature trails as a tool to promote inquiry-based science and math learning in young children	*Science Activities*	JA	EH	[37]
13	2019	Ernst, J. and Burcak, F.	Young Children's Contributions to Sustainability: The Influence of Nature Play on Curiosity, Executive Function Skills, Creative Thinking, and Resilience	*Sustainability*	JA	WOS	[38]

Table 5. *Cont.*

No.	Year	Authors	Study Title	Publication Outlet	Type	Data Source	ID
14	2019	Earle, S. and Coakley, R.	Outdoor learning in science and technology	*Teaching science and technology in the early years (3–7)*	BC	GS	[39]
15	2019	Worth, K.	Science in early learning environments	*STEM in Early Childhood Education: How Science, Technology, Engineering, and Mathematics Strengthen Learning*	BC	GS	[23]
16	2019	Wiedel-Lubinski, M.	STEM IN OUTDOOR LEARNING Rooted in Nature	*STEM in Early Childhood Education: How Science, Technology, Engineering, and Mathematics Strengthen Learning*	BC	GS	[40]
17	2019	Ashbrook, P.	The Early Years Teaching the M in STEM	*Science and Children*	JA	JS	[41]
18	2018	Anders, Y.	Goals at the Level of the Children	*Early Science Education—Goals and Process-Related Quality Criteria for Science Teaching*	BC	JS	[42]
19	2017	Carr, V., Brown, R. D., Schlembach, S., and Kochanowski, L.	Nature by design: Playscape affordances support the use of executive function in preschoolers	*Children, Youth and Environments*	JA	JS	[43]
20	2016	Wight, R. A., Kloos, H., Maltbie, C. V., and Carr, V. W.	Can playscapes promote early childhood inquiry toward environmentally responsible behaviors? An exploratory study	*Environmental Education Research*	JA	EH	[44]
21	2016	Kiewra, C. and Veselack, E.	Playing with nature: Supporting preschoolers' creativity in natural outdoor classrooms.	*The International Journal of Early Childhood Environmental Education*	JA	EH	[31]
22	2015	Tippins, D. J., Neuharth-Pritchett, S., and Mitchell, D.	Connecting Young Children with the Natural World: Past, Present and Future Landscapes	*Research in early childhood science education*	BC	GS	[45]
23	2014	Fleer, M., Gomes, J. and March, S.	Science Learning Affordances in Preschool Environments	*Australasian Journal of Early Childhood*	JA	WOS	[46]
24	2014	Klaar, S. and Öhman, J.	Children's meaning-making of nature in an outdoor-oriented and democratic Swedish preschool practice	*European Early Childhood Education Research Journal*	JA	EH	[47]
25	2014	Carr, V. and Luken, E.	Playscapes: a pedagogical paradigm for play and learning	*International Journal of Play*	JA	GS	[48]
26	2011	Worch, E. A. and Haney, J. J.	Assessing a Children's Zoo Designed to Promote Science Learning Behavior through Active Play: How Does It Measure Up?	*Children, Youth and Environments*	JA	JS	[49]
27	2011	Lynne and Bianchi, F.	Science Beyond the Classroom Boundaries for 3–7 Year Olds	*Science Beyond the Classroom Boundaries for 3–7 Year Olds*	BK	GS	[50]

Table 5. *Cont.*

No.	Year	Authors	Study Title	Publication Outlet	Type	Data Source	ID
28	2011	Luken, E., Carr, V., and Brown, R. D.	Playscapes: Designs for Play, Exploration and Science Inquiry	*Children, Youth and Environments*	JA	JS	[51]
29	2010	Hoisington, C., Sableski, N., and DeCosta, I.	A walk in the woods	*Science and Children*	JA	JS	[52]
30	2010	Waters, J. and Maynard, T.	What's so interesting outside? A study of child-initiated interaction with teachers in the natural outdoor environment	*European Early Childhood Education Research Journal*	JA	EH	[53]
31	2006	Tu, T.	Preschool science environment: What is available in a preschool classroom?	*Early Childhood Education Journal*	JA	EH	[19]

Note: types "Journal Article", "Book", and "Book Chapter" are abbreviated as JA, BK, BC, respectively; data sources "Web of Science", "Google Scholar", "Scopus", "EBSCOhost", "ProQuest", and "JSTOR" are abbreviated as WOS, GS, SCP, EH, PQ, and JS, respectively.

4. Discussion

This review aims to identify the physical factors that contribute to STEAM learning affordances in an outdoor environment for children aged three to five. Also, we wanted to explore how the addition of the 'A' (for arts) in STEAM contributed to preschoolers' outdoor learning. While this research did not find any studies specifically focused on STEAM education, which includes the arts, few studies did discuss the relationship between the arts, play, and learning environments.

Reviewed articles of this scoping review showed a multi-faceted approach, including empirical evaluation of landscape elements, pre- and post-intervention assessments through observational studies, longitudinal studies to observe sustained impacts, and comparative studies, etc., to explore the influence of outdoor environment on children's STEAM/STEM/science learning. Studies also represented educators' perceptions through surveys and interviews to understand their role during outdoor STEAM activities. Synthesis of information from those articles generated a list of STEM/STEAM/science learning behaviors of children and STEAM-activity-supportive settings. Table 6 consolidates the major outcome categories reported by the reviewed articles, highlighting the primary areas of focus within the studies. It underscores the key aspects of STEAM learning behaviors, activity-supportive settings, and the role of teachers and caregivers, providing a comprehensive overview of the findings from the reviewed literature.

Table 6. Outcome reported in reviewed papers.

Outcome Major Categories	% of the Overall Sample	Paper ID
Discussion related to the STEAM learning behavior and activities of children in an outdoor learning environment	39%	[31,33–35,38,41,42,44,47,49,50,52]
Discussion related to the STEAM-activity-supportive settings and STEAM concept development	42%	[23,28,30,32,36,37,39,43,45,46,48,51,53]
Discussion related to the role of teacher and/or caregiver in nature-based STEAM learning of children	19%	[7,19,21,27,29,40]

4.1. STEAM Learning Behaviors and Activities of Children in Outdoor Learning Environments

The reviewed articles provided a comprehensive understanding of the complementary relationships between preschool STEAM concept formation and the outdoor, natural learning landscape. According to Earle, S. and Coakley, R. [39], the foundations of science, technology, engineering, and math (STEM) are deeply connected to the natural world. Through outdoor learning that children lead, they naturally engage in key STEM processes like experimentation, inquiry, observation, problem-solving, and comparison, thereby enhancing their understanding and knowledge in these areas [23]. Tu (2006) developed tools to examine science material availability and use them in twenty (n = 20) childcare centers, finding common materials like vinyl animals and plants but limited engagement with them [19]. Young children actively engage with their environment to develop a fundamental understanding of the phenomena they are observing and experiencing [47]. Children form their own theories to make sense of everyday experiences, which assists them in embracing a more scientific perspective of the world. Cognitive research reveals that children's explorations are rooted in tangible contexts, utilizing their senses to observe, investigate, and draw conclusions from the world around them. This natural curiosity leads them to constantly ask questions and seek understanding, not in an idealized or laboratory setting but within the complexities of their everyday lives [17]. Engaging in scientific activities helps young children to appreciate and understand their environment and develop critical scientific skills. These skills include curiosity, questioning, exploration, investigation, discussion, reflection, and the formation of ideas and theories [19].

Reviewing the existing literature, this research identified different science /STEM/ STEAM learning behaviors of children covering specific learning domains that offer the most impactful experiences for children aged three to five. For future research, these behavior codes could help to observe, understand, and measure concept formations in science, technology, engineering, art, and math of young children in outdoor learning environments.

Table 7 shows that the overall identified behaviors that support STEAM learning were observing, exploring, describing/prescribing, exploring cause and effect (hypothesizing and experimenting), asking questions, building, manipulating, sorting, measuring, comparing, counting, and balancing objects. Behaviors related to arts that enrich and enhance STEM to STEAM are making art, music, language and literacy, and learning new signs and symbols.

Table 7. STEAM (science + technology + engineering + art + mathematics) behavior coding (derived from the scoping review).

	Behavior Coding	Brief Description	Reviewed Study ID
Science + Technology + Engineering	Observing	A child watches closely, hands-off (e.g., focused visual and/or auditory attention on an object or another individual).	[19,21,28–34,37–41,43–47,49,52]
	Exploring	The play focuses on exploring a play material's physical properties: hands-on/touching/ lifting/dropping, etc.	[7,19,21,23,27–33,37–41,43–47,49,52]
	Describing/Prescribing/ Predicting/Concluding	Children observe, explore, plan to act, and share their ideas with other children or teachers.	[7,19,21,30,37,39,44,47,52]
	Cause and effect (hypothesizing and experimenting)	The child makes a deliberate action and expects a certain outcome involving gravity, force, weight, distance, and height with those materials.	[7,19,21,27–34,37,39–41,44–47,49]
	Asking questions	Ask other kids or adults about certain properties of play material.	[7,19,21,30,31,34,37,38,44–47,52]
	Building/Construction	Building blocks, making a teepee with sticks, making a bridge, laying rocks on the ground, etc.	[7,21,23,27–33,38–40,43,44,46,47]
	Manipulating	Any type of manipulation of objects like moving, building, modifying, changing, etc.	[23,29,44]

Table 7. *Cont*.

	Behavior Coding	Brief Description	Reviewed Study ID
Mathematics	Sorting/Classifying	Any sort of sorting of materials based on their types, colors, textures, sizes, etc.	[7,19,21,27,29,31,32,37–41,43–46]
	Measuring	Any measuring activity includes concepts of small/big, thick/thin, etc.	[19,21,27–30,32,37–41,44,45,47,52]
	Comparing	Comparison of two or more objects or situations based on sorting, counting, and measuring.	[7,19,21,27–30,32,37–41,43–45,52]
	Counting	Any play/activity that involves counting items/objects.	[21,27,29,30,32,37–41,43–45]
	Balancing	Any activity to create balance with objects.	[21,28,32,41,44]
Arts	Art	Making art—painting, sand art, loose-part art, art with leaves, etc.	[7,19,21,23,28,39,40,47]
	Music	Making music, singing, or making sounds.	[21,39]
	Language and Literacy, Signs/Symbols	Reading, reciting, learning new words, new symbols or signage, etc.	[19,21,27,30,32,37,39,40,43–46,52]

4.2. STEAM-Activity-Supportive Settings and STEAM Concept Development

The scoping review expanded our ideas of how natural outdoor environments accommodate diverse STEAM affordances to advance preschoolers' concept development in science, engineering, math, etc. They can be seen as a living school—dynamic and full of wonders for young children. It is an effective educational setting for young children, fostering science learning through exploration and discovery. It encourages critical thinking and problem-solving as they investigate elements like leaves, puddles, or insects, turning the outdoors into a practical scientific laboratory for development [37]. The outdoor environment offers a broader range of experiences than the indoor classroom. With their ever-changing elements and seasonal variations, outdoor learning environments offer a less predictable setting than a traditional classroom, fueling curiosity and interest in STEM concepts [52]. This constantly evolving natural backdrop encourages deeper inquiry and exploration, with nature readily presenting surprises to those who engage with the outdoors [40]. In a natural outdoor setting, children can interact with natural elements like leaves and sticks, engage with tactile experiences such as soil, and foster a connection with the natural world, fostering a sense of appreciation. Such environments allow children to enhance their creative abilities and critical thinking skills, which are crucial for scientific and technological exploration [35]. Observations suggest that naturalistic play settings can enhance behaviors like creativity, social interaction, and detailed observation, which are advantageous for early STEM (science, technology, engineering, and mathematics) education [35].

The scoping review reveals that in an outdoor environment, young children actively explore and manipulate objects, and also closely examine their characteristics like texture, size, or material. These properties influence how children use landscape elements during outdoor time; for instance, they use large, sturdy branches for constructing hut walls and softer materials for making a spider's cushion [49]. Analyzing the selected resources, this review associated the STEAM learning behaviors and activities (identified in Table 7) with specific outdoor STEAM-activity-supportive settings (Table 8).

Table 8. STEAM learning behaviors and activities are associated with the outdoor STEAM-activity-supportive settings.

No.	ID	STEAM-Activity-Supportive Setting	STEAM Learning Behaviors	STEAM Concept Formation
1.	[23,27,30–33,40,43,44,46–48,51]	Sand Play/ Earth Play/ Mud/ Digging	Cause/Effect, Construction, Manipulative, Observation, Exploration	Sand engages children because it is easy to move, manipulate, mold, dig, shift, sculpt, and pour. Also, they learn about forces, mixing, and material properties.
2.	[7,23,30,32,33,40,41,43,46–48,51]	Water Play	Cause/Effect, Construction, Manipulative, Observation, Exploration	Children can solve problems while predicting which items will float or sink in a water-filled container.
3.	[30,43,44,46,48,51]	Primary Pathways	Exploration	Tactile properties of materials.
4.	[27,30,43,44,46,48]	Sensory Pathway	Observation, Exploration.	Tactile properties of materials; senses: soft, smooth, slippery, shiny, etc.
5.	[7,19,23,27–34,40,43–46,48,51–53]	Plants: Trees, Shrubs, Edible Garden	Observation, Exploration, Experiments, Natural Art, Counting, Sorting, Measuring, Comparing	Gardens provide a workspace for children to raise questions about the natural world, take hands-on action, and seek answers through observation, exploration, and data collection.
6.	[27,31,33,43,46,53]	Sensory Garden/ Grass Mazes and Tall Grass Areas	Observation, Exploration, Experiments, Natural Art, Counting, Sorting, Measuring, Comparing	Sensory exploration outdoors can include touching the bark of a tree or the grass, seeing the birds building nests or leaves blowing, hearing the sounds carried by the wind or the honking of a car horn nearby, smelling freshly cut grass, or the fragrance of flowers.
7.	[23,39,40,46]	Compost Pile	Observation, Exploration, Experiments, Construction, Teamwork	Children can place leaves, plant cuttings, and food scraps in a compost bin or pile, along with worms, to help "mix up" the compost.
8.	[29,33,34,37,43]	Dry Creek Beds	Observation, Exploration, Experiments, Construction, Teamwork	Varied textures and materials in the creek bed aid sensory development, observing the flow and effects of water on the landscape.
9.	[23,29–31,44,51]	Large Blocks and Natural Construction (Construction/ Engineering)	Experiment, Exploration, Observation, Construction, Teamwork	Making towers and bridges, recognizing shapes in buildings, fences, triangles, squares, diagonals, rectangles, and circles.
10.	[7,23,27,28,30–33,37,40,41,43,44,46,48,51–53]	Loose Parts Play	Experiment, Exploration, Observation, Counting, Sorting, Measuring, Comparing	The properties of items can be investigated using a magnifying glass to examine shells, rocks, feathers, or objects discovered in nature.
11.	[19,23,28,29,33,34,39,43,44,53]	Wildlife/ Bird, Butterfly, and Pollinator Habitat	Observation, Exploration, Language, Signs	Using their naturalist intelligence, children can discriminate among living things (plants and animals) and develop sensitivity to the features of the natural world (clouds and rock configurations).
12.	[31]	Acoustic Play Settings	Music, Language, Exploration, Observation, Teamwork, Signs	Preschoolers can experiment cause-and-effect relationships, such as exploring how different materials and actions produce varied sounds.
13.	[23,30,31,48,51]	Art Area	Art, Language, Exploration, Observation, Teamwork, Signs	Children can manipulate different materials—paints, clay, papers, and natural objects—and learn about textures, colors, shapes, and spatial relationships.

Table 8. *Cont*.

No.	ID	STEAM-Activity-Supportive Setting	STEAM Learning Behaviors	STEAM Concept Formation
14.	[19,23,30]	Outdoor Reading and Language Play	Language, Literacy, Reading, Signs	Children can create outdoor stories, identify, match, speak, make symbols, and write. Naming/identifying birds and insects including spiders, ladybirds, beetles, ants, worms, caterpillars, butterflies, and centipedes.
15.	[19,31]	Signage: Directional, Informational, Identification, Regulatory, and Inspirational signs.	Language, Literacy, Reading, Signs	Provide a comprehensive communication system of information that children of all ages, cultural backgrounds, and abilities can easily read and understand; signed description to explain the observed phenomenon.
16.	[23,30,31]	Outdoor Classroom	Cause/Effect, Construction, Manipulative, Observation, Exploration	High-quality play spaces incorporate diverse natural elements for children to play and learn with, such as trees, stumps, boulders, tall grass, water, pebbles, mounds, and slopes. Learning takes place outdoors and differs from learning indoors.
17.	[23,30,49]	Pretend and Performance/ Decks, Platforms, and Stages	Performance, Signs, Language, Observation	Role-play props, e.g., tea-sets, dolls, soft animals. Children learn to question, predict, and experiment with different roles and observe outcomes.
18.	[23,29,31–33,41,43,44,47,48,51,53]	Topography and Landforms / Mounds and Slopes	Cause/Effect, Exploration	Forces, push-pull, twists, taut, friction, construction, gravity, speed acceleration, deceleration.
19.	[31,39,43,48,51]	Multipurpose Lawn	Diverse Affordances	Open, grassy spaces support various types of play and exploration foundational for early science learning.
20.	[28,30–32,43,44,46,47,49]	Fixed Play Structures	Diverse Affordances	Understanding friction, running up and down to explore physical properties like gravity, etc., using different sizes and loads, and rolling down (gravity, force, motion, etc.).
21.	[19,44,46,48,51,53]	Moveable Play Structures/ Portable Toys and Equipment	Diverse Affordances	Crawling through tunnels, running, chasing, sitting, dancing, hopping, and jumping. Rolling, balancing, throwing, catching (gravity, force, motion, etc.).
22.	[30,31,43,44,48,51]	Natural Healing and Relaxation Area	Observation, Exploration, Experiments, Natural Art	Light, shadows, weather variations, etc. Scenic settings rich in natural elements like plants, water features, and soft, natural textures afford young children to engage in mindful observation and exploration.

4.3. The Role of Teacher/Caregiver in Nature-Based STEAM Learning of Children

The primary focus of the scoping review was to identify nature-based affordances in outdoor learning and associated STEAM behaviors/activities of preschoolers. However, the review provided valuable insights regarding the critical role of teachers/caregivers. Teachers play the most important moderator role in this environment–behavior relationship of nature-based early STEAM concept formation. Loris Malaguzzi, a key figure in the development of Reggio Emilia's approach to early childhood education, emphasized the importance of children's active engagement in learning. Malaguzzi believed that learning is a dynamic process, significantly shaped by children's experiences, interactions, and the environment provided to them. His perspective underlines that education is not just about transmitting knowledge from teacher to student but involves a more complex interplay where children construct knowledge through their activities, exploration, and the resources available to them. This review highlights the "environment as a third teacher" concept introduced by the Reggio Emilia approach in Italy [21]. Nature encompasses everything around us—the ground, sky, wind, rocks, and rain—including all elements of the ecosystem and people. It is everywhere in cities, suburbs, and rural areas, making it accessible for educational purposes. This understanding is crucial for teachers looking to integrate nature into outdoor learning. Nature is not distant; it is a vital part of every community and an aspect of daily life. Recognizing and embracing this concept is key for educators to effectively utilize nature in its various forms within their school environments [42].

Both indoor and outdoor learning require teachers to organize and support children's educational journey effectively. Teachers must be aware of the children's experiences, the play they create, and what captivates or fails to engage them. It is also important for educators to interpret the potential significance of children's inquiries, the concepts they are formulating, and their methods of expressing their thoughts. To achieve this, teachers should take on the roles of observers, closely monitoring the children's explorations [23]. Teachers can actively engage children in nature-based education by guiding them to use their senses to observe, listen, smell, and touch, similar to the methods used by scientists [37]. The inclusion of nature-based affordances in early learning often stems from teachers' understanding of it and their capacity or inclination to utilize the resources available at their current location. At the other end of the spectrum, the misconception of teachers that nature is a distant entity restricts their imagination and efforts to include nature in the learning process.

4.4. Limitations, Delimitations, and Future Research

Firstly, the specification of the outcomes of search terms remained broad, and this was done deliberately to obtain a broad overview of how the nature-based outdoor learning landscape influences STEAM learning of preschoolers. However, this scoping review showed that STEAM-based outdoor learning is quite a new topic, and there are no assessment guidelines that can give us an idea of which opportunities in the outdoor learning landscape can maximize STEAM learning and how we can define/observe/measure the STEAM learning behaviors of preschoolers. Moreover, the inclusion of arts with STEM identified different affordances in outdoor learning environments, potentially influencing cognitive and creative development differently than STEM-focused formal programs. Future research can benefit from using the meta-analysis technique to identify appropriate approaches for evaluating children's learning progress during STEAM-based outdoor activities and the affordances of a preschool outdoor learning landscape.

There was also the fact that the domains of this review hardly coincided with each other altogether in the reviewed studies, and only two studies discussed the affordances of science learning [15,32]. However, the target of this study was to find the relationship between STEAM learning of preschoolers and the outdoor learning landscape. The reviewed studies covered a range of learners, including infant/toddler and primary/elementary children. Numerous papers mentioned outdoor learning environments and play affordances. To keep focused on STEAM learning, this scoping review eliminated those articles that did not mention anything about STEAM/STEM/science learning. Although those affordances were closely related to cognitive development. The lack of inclusion of those studies could be identified as a significant limitation. Additionally, the study characteristics identified in this review revealed that all the research was conducted in developed countries, limiting the generalizability of the findings to developing regions. This context constrains the applicability of the results across diverse socioeconomic backgrounds and education systems. This scoping review did not address the specific learning needs of children with learning disabilities, such as those with ASD, dyslexia, ADHD, and others. Acknowledging the significant individual differences in learning levels among children, we recommend that the nature-based learning opportunities for children with learning disabilities be researched and reviewed separately to comprehensively understand their unique needs and benefits. The research topic is interdisciplinary. A scoping review is an appropriate methodology in the interdisciplinary field of outdoor learning environment research, incorporating articles from diverse disciplines that have enriched the conclusions drawn.

5. Conclusions

The integration of science and technology into outdoor play areas provides children with unique features and opportunities that are not available in a traditional kindergarten setting [7]. The design of outdoor learning environments can significantly impact STEAM education through intentional design elements. These elements can provide STEAM learning opportunities and create informal settings essential for STEAM education. Children are presented with diverse natural resources to incorporate into their play, fostering creativity, social interaction, and complex activities such as construction projects. On the other hand, playgrounds are not as effective in encouraging STEM-related play because the fixed nature of playground equipment restricts children's freedom to explore and implement their ideas [32]. This review identified the STEAM learning affordances of an outdoor learning environment that enhances preschool-aged children's engagement in science, technology, engineering, arts, and mathematics (STEAM) learning through their interactions with nature. This could encompass cognitive development by fostering curiosity, creativity, and problem-solving skills in early childhood.

This scoping review identified several STEAM learning behaviors of children and STEAM-activity-supportive settings, which can guide design modification efforts to transform mundane playgrounds into engaging and affordance-rich outdoor learning landscapes to stimulate young children's STEAM learning. These settings and affordances that foster a conducive learning atmosphere could significantly enhance the quality of early childhood STEAM education. The outcomes of this scoping review could potentially inform policy and curriculum development in early childhood education by integrating more outdoor, nature-based STEAM learning experiences into preschool formal/informal education. Adapting these STEAM-learning-supportive settings to develop existing childcare/preschool outdoor environments could be a significant and pivotal step in moving towards more experiential and environment-based learning approaches in early childhood education.

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References

1. Louv, R. *Last Child in the Woods: Saving Our Children from Nature-Deficit Disorder*; Algonquin Books: Chapel Hill, NC, USA, 2008.
2. Cui, J.; Natzke, L. Early Childhood Program Participation: 2019. First Look. NCES 2020-075. Available online: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2020075REV (accessed on 23 May 2024).
3. Is the, U.S. Falling Behind in STEM Education? Available online: https://www.codewizardshq.com/us-behind-in-stem-education/ (accessed on 23 May 2024).
4. Armstrong, S.J.; Fukami, C.V. *The SAGE Handbook of Management Learning, Education and Development*; Sage: London, UK, 2009.
5. Cohen, L.E.; Waite-Stupiansky, S. *STEM in Early Childhood Education*; Routledge: New York, NY, USA, 2020.
6. Torquati, J.; Cutler, K.; Gilkerson, D.; Sarver, S. Early childhood educators' perceptions of nature, science, and environmental education. *Early Educ. Dev.* **2013**, *24*, 721–743. [CrossRef]

7. Speldewinde, C.; Campbell, C. 'Bush kinders': Developing early years learners technology and engineering understandings. *Int. J. Technol. Des. Educ.* **2023**, *33*, 775–792. [CrossRef]
8. Moore, R.C.; Marcus, C.C. Healthy planet, healthy children: Designing nature into the daily spaces of childhood. In *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*; Wiley: Hoboken, NJ, USA, 2008; Volume 385.
9. Gullo, D.F. *Understanding Assessment and Evaluation in Early Childhood Education*; Teachers College Press: New York, NY, USA, 2005; Volume 95.
10. Melhuish, E.C. *Provision of Quality Early Childcare Services: Synthesis Report*; BIROn—Birkbeck Institutional Research Online, University of London: London, UK, 2016.
11. Gibson, E.J.; Pick, A.D. *An Ecological Approach to Perceptual Learning and Development*; Oxford University Press: Oxford, UK, 2000.
12. Edwards, C.P.; Gandini, L. The Reggio Emilia approach to early childhood education. In *Handbook of International Perspectives on Early Childhood Education*; Routledge: New York, NY, USA, 2018; pp. 365–378.
13. Cameron, C.E. *Hands on, Minds on: How Executive Function, Motor, and Spatial Skills Foster School Readiness*; Teachers College Press: New York, NY, USA, 2018.
14. David, T.G.; Weinstein, C.S. *Spaces for Children: The Built Environment and Child Development*; Springer: Greer, SC, USA, 2013.
15. Ernst, J. Early Childhood Educators' Preferences and Perceptions Regarding Outdoor Settings as Learning Environments. *Int. J. Early Child. Environ. Educ.* **2014**, *2*, 97–125. Available online: https://eric.ed.gov/?id=EJ1108039 (accessed on 23 May 2024).
16. Striniste, N.A.; Moore, R.C. Early childhood outdoors: A literature review related to the design of childcare environments. *Child. Environ. Q.* **1989**, *6*, 25–31. Available online: https://www.jstor.org/stable/41514704 (accessed on 23 May 2024).
17. Worth, K. *The Power of Children's Thinking*; National Science Foundation: Arlington, VA, USA, 1999; Volume 2.
18. Trundle, K.C. Teaching science during the early childhood years. In *Best Practices and Research Base*; Springer: New York, NY, USA, 2010. [CrossRef]
19. Tu, T. Preschool science environment: What is available in a preschool classroom? *Early Child. Educ. J.* **2006**, *33*, 245–251. [CrossRef]
20. Chalufour, I.; Worth, K. *Discovering Nature with Young Children: Part of the Young Scientist Series*; Redleaf Press: Saint Paul, MN, USA, 2003.
21. Bartolini, V.C. *Creating a Reggio-Inspired STEM Environment for Young Children*; Redleaf Press: Saint Paul, MN, USA, 2021.
22. Worth, K. Science in Early Childhood Classrooms: Content and Process. 2010. Available online: https://ecrp.illinois.edu/beyond/seed/worth.html (accessed on 23 May 2024).
23. Worth, K. Science in early learning environments. In *Stem in Early Childhood Education: How Science, Technology, Engineering, and Mathematics Strengthen Learning*; Routledge: New York, NY, USA, 2019; pp. 3–21.
24. Arksey, H.; O'malley, L. Scoping studies: Towards a methodological framework. *Int. J. Soc. Res. Methodol.* **2005**, *8*, 19–32. [CrossRef]
25. Peters, M.; Godfrey, C.; McInerney, P.; Soares, C.B.; Khalil, H.; Parker, D. Methodology for JBI scoping reviews. In *The Joanna Briggs Institute Reviewers Manual 2015*; Joanna Briggs Institute: Adelaide, Australia, 2015; pp. 3–24.
26. Paez, A. Gray literature: An important resource in systematic reviews. *J. Evid.-Based Med.* **2017**, *10*, 233–240. [CrossRef] [PubMed]
27. Speldewinde, C.; Campbell, C. Bush kinders: Enabling girls' stem identities in early childhood. *J. Adventure Educ. Outdoor Learn.* **2023**, *23*, 270–285. [CrossRef]
28. Campbell, C.; Speldewinde, C. Bush kinders in Australia: A creative place for outdoor stem learning. In *Children's Creative Inquiry in STEM*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 185–204.
29. Campbell, C.; Speldewinde, C. Affordances for Science learning in "Bush kinders". *Int. J. Innov. Sci. Math. Educ.* **2020**, *28*, 1–13. [CrossRef]
30. Miller, A.R.; Saenz, L.P. Exploring relationships between playspaces, pedagogy, and preschoolers' play-based science and engineering practices. *J. Child. Educ. Soc.* **2021**, *2*, 314–337. [CrossRef]
31. Kiewra, C.; Veselack, E. Playing with Nature: Supporting Preschoolers' Creativity in Natural Outdoor Classrooms. *Int. J. Early Child. Environ. Educ.* **2016**, *4*, 70–95. Available online: https://eric.ed.gov/?id=EJ1120194 (accessed on 23 May 2024).
32. Weiser, L.E. Young Children's Free Play in Nature: An Essential Foundation for STEM Learning in Germany. In *Play and STEM Education in the Early Years: International Policies and Practices*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 85–103.
33. Worch, E.; Odell, M.; Magdich, M. Engaging Children in Science Learning Through Outdoor Play. In *Play and STEM Education in the Early Years: International Policies and Practices*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 105–122.
34. Skalstad, I.; Munkebye, E. Young children's questions about science topics when situated in a natural outdoor environment: A qualitative study from kindergarten and primary school. *Int. J. Sci. Educ.* **2021**, *43*, 1017–1035. [CrossRef]
35. Tunnicliffe, S.D. *Emerging Biology in the Early Years: How Young Children Learn about the Living World*; Routledge: New York, NY, USA, 2020.
36. Krogh, S.L.; Morehouse, P. *The Early Childhood Curriculum: Inquiry Learning Through Integration*; Taylor & Francis: Abingdon, UK, 2020.
37. Lee, C.K.; Ensel Bailie, P. Nature-based education: Using nature trails as a tool to promote inquiry-based science and math learning in young children. *Sci. Act.* **2019**, *56*, 147–158. [CrossRef]
38. Ernst, J.; Burcak, F. Young children's contributions to sustainability: The influence of nature play on curiosity, executive function skills, creative thinking, and resilience. *Sustainability* **2019**, *11*, 4212. [CrossRef]

39. Earle, S.; Coakley, R. Outdoor learning in science and technology. In *Teaching Science and Technology in the Early Years (3–7)*; Routledge: New York, NY, USA, 2019; pp. 57–75.
40. Wiedel-Lubinski, M. STEM in outdoor learning: Rooted in nature. In *STEM in Early Childhood Education*; Routledge: New York, NY, USA, 2019; pp. 182–205.
41. Ashbrook, P. The Early Years: Teaching the M in STEM. *Sci. Child.* **2019**, *56*, 16–17. Available online: https://www.jstor.org/stable/26901400 (accessed on 23 May 2024). [CrossRef]
42. Anders, Y.; Hardy, I.; Pauen, S.; Steffensky, M.; Ramseger, J.; Sodian, B.; Tytler, R. Goals at the Level of the Children. In *Early Science Education—Goals and Process-Related Quality Criteria for Science Teaching*, 1st ed.; "Haus der kleinen Forscher" Foundation, Ed.; Verlag Barbara Budrich: Opladen, Germany, 2018; Volume 5, pp. 41–74.
43. Carr, V.; Brown, R.D.; Schlembach, S.; Kochanowski, L. Nature by design: Playscape affordances support the use of executive function in preschoolers. *Children, Youth Environ.* **2017**, *27*, 25–46. Available online: https://www.jstor.org/stable/10.7721/chilyoutenvi.27.2.0025 (accessed on 23 May 2024). [CrossRef]
44. Wight, R.A.; Kloos, H.; Maltbie, C.V.; Carr, V.W. Can playscapes promote early childhood inquiry towards environmentally responsible behaviors? An exploratory study. *Environ. Educ. Res.* **2016**, *22*, 518–537. [CrossRef]
45. Tippins, D.J.; Neuharth-Pritchett, S.; Mitchell, D. Connecting young children with the natural world: Past, present and future landscapes. In *Research in Early Childhood Science Education*; Springer: Dordrecht, The Netherlands, 2015; pp. 279–297. [CrossRef]
46. Fleer, M.; Gomes, J.; March, S. Science learning affordances in preschool environments. *Australas. J. Early Child.* **2014**, *39*, 38–48. [CrossRef]
47. Klaar, S.; Öhman, J. Children's meaning-making of nature in an outdoor-oriented and democratic Swedish preschool practice. *Eur. Early Child. Educ. Res. J.* **2014**, *22*, 229–253. [CrossRef]
48. Carr, V.; Luken, E. Playscapes: A pedagogical paradigm for play and learning. *Int. J. Play* **2014**, *3*, 69–83. [CrossRef]
49. Worch, E.A.; Haney, J.J. Assessing a Children's Zoo Designed to Promote Science Learning Behavior through Active Play: How Does It Measure Up? *Child. Youth Environ.* **2011**, *21*, 383–407. Available online: https://www.jstor.org/stable/10.7721/chilyoutenvi.21.2.0383 (accessed on 23 May 2024). [CrossRef]
50. Bianchi, L.; Feasey, R. *Science Beyond the Classroom Boundaries for 3–7 Year Olds*; Open University Press: Maidenhead, UK, 2011.
51. Luken, E.; Carr, V.; Brown, R.D. Playscapes: Designs for Play, exploration and science inquiry. *Child. Youth Environ.* **2011**, *21*, 325–337. Available online: http://www.jstor.org/stable/10.7721/chilyoutenvi.21.2.0325 (accessed on 23 May 2024). [CrossRef]
52. Hoisington, C.; Sableski, N.; DeCosta, I. A walk in the woods. *Sci. Child.* **2010**, *48*, 27. Available online: https://foundationsofscienceliteracy.edc.org/wp-content/uploads/2019/07/SC-Vol48-2.pdf (accessed on 23 May 2024).
53. Waters, J.; Maynard, T. What's so interesting outside? A study of child-initiated interaction with teachers in the natural outdoor environment. *Eur. Early Child. Educ. Res. J.* **2010**, *18*, 473–483. [CrossRef]

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