Part 17 / Strand 17

Science Education In Primary And Pre-Primary Learning Contexts

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Science education from early childhood through primary school, with wide ranging foci including science pedagogies, children's learning, innovative teaching practices, teacher education, social and cultural aspects of science engagement, and family involvement.

Sub-themes:

1) Children's science engagement
2) Pedagogies for science in the early years
3) Emergent Science
4) Early childhood science instruction
5) Primary science instruction

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Strand 17: Science Education In Primary And Pre-Primary Learning Contexts

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Framing Early Science Learning

This chapter in the eProceedings, related to the *Science Education in Primary and Pre-Primary Learning Contexts* strand, brings into focus a formative phase in learners' engagement with science, where foundational dispositions, identities, and ways of knowing begin to take shape. Across this strand, science education is understood not simply as the acquisition of early concepts, but as a situated and relational process through which young learners come to make sense of their natural and designed world. Contemporary research increasingly positions early experiences of science education as an active and socially mediated endeavour, where children engage through questioning, observing, exploring, and refining ideas across diverse contexts.

Learning Through Participation, Design And Experience

Across the contributions in this chapter, science learning is consistently framed as participation in scientific practices rather than the passive reception of knowledge. Inquiry, experimentation, engineering design, computational thinking, and multimodal meaning-making are positioned as central approaches through which children construct understanding. Evidence continues to highlight the importance of engaging learners in meaningful science experiences from the early years, with well-designed interventions contributing to sustained learning outcomes. Importantly, these practices extend beyond the classroom. Several papers emphasise the pedagogical potential of outdoor and place-based environments, including schoolyards and green spaces, where learners engage with biodiversity, ecosystems, and environmental processes through embodied and sensory experience.

A key insight emerging across the chapter is that access to engaging or resource-rich environments does not, in itself, guarantee meaningful learning. Whether in outdoor or digital contexts, high levels of activity and participation do not necessarily lead to conceptual understanding, which highlights why the design of pedagogical environments is critical. Across the contributions, inquiry-based materials, learning–teaching sequences, and digital tools are shown to require careful structuring to support a progression from exploration to explanation. This includes balancing structure and openness to ensure that learners are supported in moving beyond interaction towards reasoning and meaning making. Within this, the role of the teacher remains central as a mediator of learning, guiding reflection and supporting conceptual development.

Agency, Coherence, And Contemporary Challenges

Young learners are consistently positioned across these contributions as capable, creative, and active participants in science learning. Creativity is framed as integral to scientific thinking, particularly within contexts such as engineering design and computational activity, while collaboration, negotiation, and even resistance, are understood as productive elements of learning. At the same time, several contributions highlight issues of equity, access, and inclusion, drawing attention to how socioeconomic factors, access to digital resources, and the design of learning environments shape opportunities for meaningful participation.

Alongside this emphasis on participation, the strand also engages with questions of conceptual coherence and disciplinary integrity. Several papers highlight the importance of structuring learning around key scientific ideas and supporting progression towards more sophisticated understandings. This includes the design of learning–teaching sequences and the introduction of complex scientific perspectives, such as elements of contemporary physics, within primary education. Such work reflects a broader commitment to aligning early science education with the epistemological foundations of the discipline, while remaining responsive to learners' developmental trajectories.

Finally, the contributions connect strongly to broader societal priorities, particularly sustainability and digital transformation. Science education is positioned as a means of fostering awareness of human–nature interdependence and supporting engagement with environmental challenges, often grounded in local and place-based contexts. At the same time, the increasing presence of digital technologies in children's lives raises important questions about the quality and depth of learning in digital environments. While these tools offer new opportunities for engagement, their value depends on thoughtful pedagogical design and alignment with principles of effective learning.

Taken together, the papers in this chapter reflect a dynamic and evolving field that is attentive to the complexities of early science learning. They highlight the importance of designing learning environments that are pedagogically intentional, conceptually coherent, and socially responsive, while recognising young learners as capable, creative, and engaged participants in science. In doing so, the strand contributes to ongoing conversations about how primary and pre-primary science education can support more meaningful, inclusive, and future-oriented educational practices.

Beyond The Slide: Rethinking Playgrounds As Learning Spaces

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Outdoor spaces have been shown to function as powerful pedagogical environments, enriching children's understanding of and connection with the world around them. Yet, some schoolyards remain little more than concrete jungles, devoid of natural elements and thus silencing nature's invitation to discover.

This preliminary study explores the potential of a Spanish preschool playground as a context for scientific learning. By analysing both teachers' perceptions of the playground and children's use of it, a proposal for change was developed and implemented. The findings reveal that even small modifications to the physical environment can foster changes in children's behaviour, increasing their engagement in scientific activities. Following these changes, children engaged more explicitly with scientific concepts and skills, what created opportunities to extend their interests within the classroom. These findings also highlight the central role of teachers in such spaces. Fostering meaningful science learning in free-play outdoor environments requires more than just physical transformations; it also demands that educators rethink their roles and actively support children's scientific exploration.

Keywords: Early-childhood Education, science learning, outdoor play

Introduction

Children engage with the world as if in constant dialogue with it. Driven by an innate curiosity, "they question, observe, investigate, experiment, and question again" (Raven & Wenner, 2023, p. 485). Unaware of their own scientific potential, children participate in cycles of action and reflection that help them navigate their environment and lay the foundations for their interactions with it (Pedreira & Márquez, 2019).

It is through play that this dialogue unfolds. In its spontaneous and creative nature, play provides a particularly rich context for children to explore and reflect on everyday scientific phenomena (Gomes & Fleer, 2020). This potential is especially evident in outdoor environments, where diverse sensory stimuli invite multiple forms of exploration (Speldewinde, 2024), from the crunch of leaves underfoot to the scent of flowers in bloom.

Such dynamic environments can inspire open-ended play, physical activity, risk-taking, emotional engagement, exploration, and interaction with both peers, and the environment (Speldewinde, 2024). In doing so, they become powerful allies in nurturing scientific learning. Outdoor spaces encourage children to actively engage with their surroundings, creating opportunities for meaningful, hands-on encounters with scientific ideas (Lee & Ensel Bailie, 2020). Nevertheless, despite research suggesting that it is possible to go beyond the strictly ludic in these contexts, linking playing and learning in a meaningful way (Sanz et al., 2021), the potential of play to foster scientific learning remains underexplored (Gomes & Fleer, 2020). Play is frequently positioned as separate from learning, a dichotomy that becomes even more pronounced in outdoor settings (Lee & Ensel Bailie, 2020). As a result, outdoor playtime is frequently treated as a break from formal learning rather than as a pedagogical opportunity.

In recent years, however, this trend seems to be reversing. Schoolyards are increasingly being revalued as educational spaces in which children can engage with their surroundings and learn from them (Sanz et al., 2021). Despite this growing recognition, many schoolyards remain barren and lack natural elements (Mateo et al., 2021). Motivated by this reality, we immersed ourselves in the daily life of a Spanish preschool, analysing its schoolyard, teachers' perceptions of its educational potential and how children use it. Based on this analysis, we introduced physical modifications to the schoolyard aiming to explore how these changes influence children's physical, social, and cognitive activities, with a particular emphasis on children's scientific activities.

Study Design

The study was designed as a preliminary case study (Yin, 2014) conducted in a Spanish preschool that had initiated a process of schoolyard naturalization. The aim was to understand this preschool's needs and use these insights to design and implement playground modifications that could support children's scientific learning. To achieve this, we engaged in an in-depth immersion in the daily life of this preschool, where the first author was completing a student-teacher placement at the time.

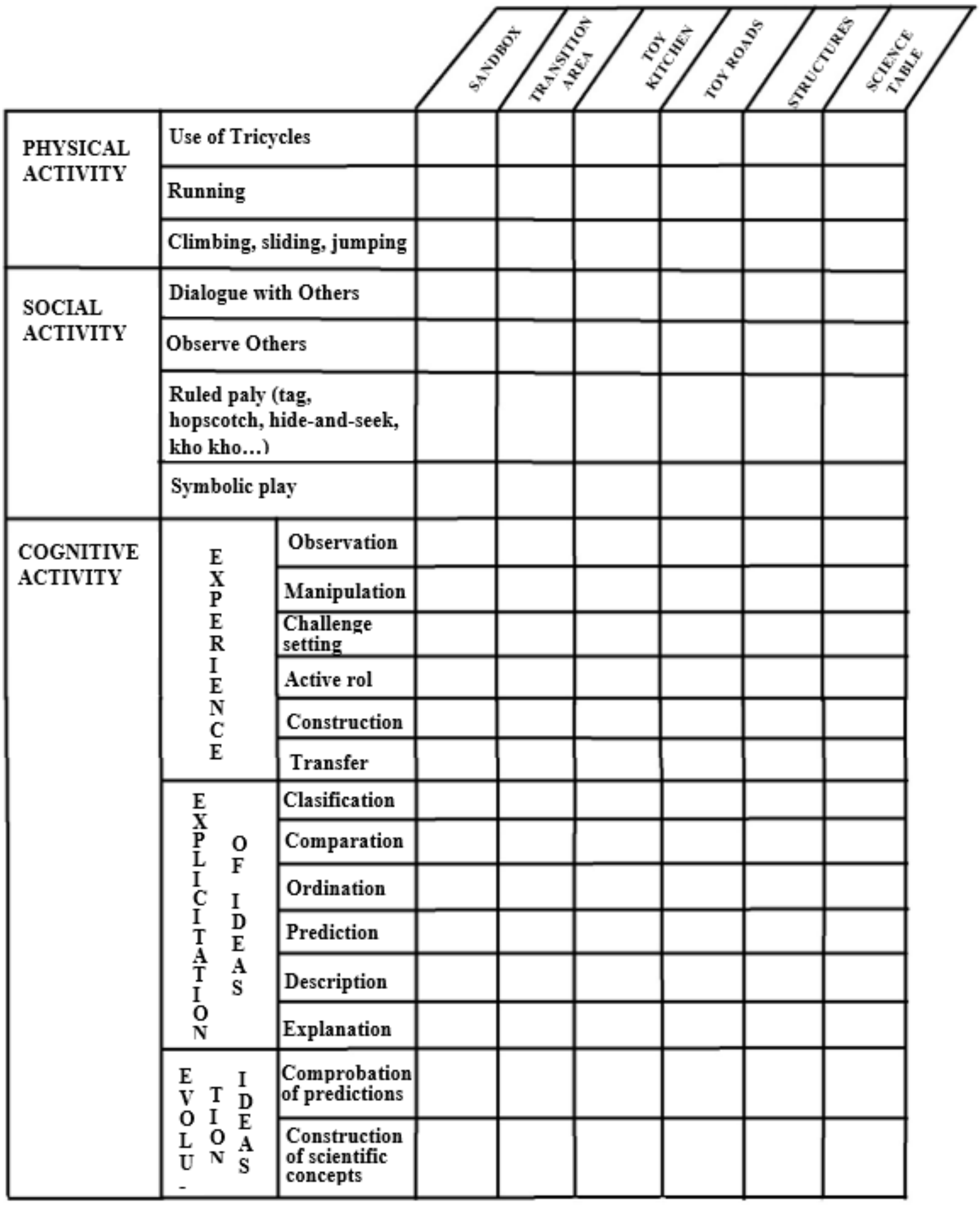
To explore the school's needs, we conducted semi-structured interviews with nine teachers. The interviews focused on teachers' perceptions of the schoolyard, including its strengths, limitations, and educational potential. Teachers were asked about their views on the space, how science learning was currently supported (or could be supported), and how the playground was used in their daily practice.

Following the interviews, we analysed how children and teachers actually used the playground. We began by identifying the different areas within it, considering the materials available and the activities that typically took place in each area to differentiate them. The areas included in the analysis are shown in the top row of Figure 1. Over a three-week period, we observed children's and teachers' behaviour during recess, the only time the playground was used. Each 30-minute recess involved approximately 170 children aged 3 to 5 years, who played freely in the playground. Given the large number of children and the size of the space, direct observation posed significant challenges. To address these, we focused on identifying recurring behavioural patterns and recorded only actions that were consistently observed across multiple days.

Data were collected through field notes and photographs. Observed activities were categorized as physical, social, or cognitive, following the example of Peinado Alamillo et al. (2022). Cognitive activities were further divided into three subcategories: experience with reality, explicitation of ideas, and evolution of ideas. These subcategories align with the three stages of the scientific activity defined by Pedreira and Márquez (2019). The observation instrument used for data collection is presented in Figure 1.

Data from all sources were triangulated to identify needs and potentialities. These findings informed the design and implementation of physical modifications to the playground. The same observation instrument was subsequently used to analyse changes in children's activities after the intervention, enabling direct comparison. The limitations of this approach are acknowledged, in line with the preliminary nature of the study.

Figure 1. Analysis template used to identify changes in children's scientific actions adapted from Pedreira and Márquez (2019) and Peinado Alamillo et al. (2022).



			SANDBOX	TRANSITION AREA	TOY KITCHEN	TOY ROADS	STRUCTURES	SCIENCE TABLE
PHYSICAL ACTIVITY		Use of Tricycles						
		Running						
		Climbing, sliding, jumping						
SOCIAL ACTIVITY		Dialogue with Others						
		Observe Others						
		Ruled paly (tag, hopscotch, hide-and-seek, kho kho...)						
		Symbolic play						
COGNITIVE ACTIVITY	EXPERIENCE	Observation						
		Manipulation						
		Challenge setting						
		Active rol						
		Construction						
		Transfer						
	EXPLICITATION OF IDEAS	Clasification						
		Comparation						
		Ordination						
		Prediction						
		Description						
		Explanation						
	EVOLU-TION IDEAS	Comprobation of predictions						
		Construction of scientific concepts						

Findings

The interviews revealed that teachers perceive spaces as active educational agents that shape children's actions. Consequently, they emphasized ongoing collaborative efforts to transform school spaces into welcoming environments that promote learning. This perspective also extended to outdoor areas, which teachers recognized as contexts in which children learn both in and from their surroundings.

Most teachers valued recent renovations to the playground, particularly the addition of materials such as tricycles, strainers, and building blocks, which they associated with scientific learning (e.g., "*Children learn science outdoors when playing with tricycles and strainers*."). However, they also acknowledged that some areas remained underused or lacked a clear educational purpose. On this behalf, teachers expressed appreciation for our intervention in helping them reflect on the playground's potential, noting the importance of collective reflection (e.g., *"It is necessary not to have just one mind thinking, but several minds discussing."*).

When asked about their own use of the schoolyard, only one teacher reported using it outside recess. Most described adopting a non-interventionist role during break time, allowing children to interact freely with the environment. Only one teacher explicitly questioned this approach, suggesting that educators' roles in outdoor play may need to be reconsidered if the aim is to foster scientific learning.

Observational data showed that children's activities varied notably depending on the area and materials available. Overall, social, physical, and cognitively driven activities, particularly those involving direct interactions with their surroundings, were the most common (Figure 2, next page). Following the modifications, overall activity increased, with a particularly noticeable rise in cognitive engagement among children (Figure 2).

In Figure 2, blue shading indicates the activities observed in each playground area. Each cell is divided into two sections: the left side represents activities observed before the modifications, and the right side those observed afterward. The intensity of the blue tone is proportional to the number of activities observed, so that a darker tone indicates a greater number of activities. Consequently, a cell with a lighter tone on the left and a darker tone on the right shows an increase in the number of activities carried out after the modification of the playground. It is important to note that the frequency of each type of activity was not considered. An activity was considered as long as at least one child engaged in it. Post-intervention changes were analysed by comparing each activity with its occurrence prior to the modifications, without cross-area or frequency comparisons.

Activities involving the explicit articulation and evolution of ideas were the least frequently observed during recess. Although frequency was not quantitatively analysed, these interactions occurred far less often than physical activities, which were more prominent in practice despite their limited representation in the table.

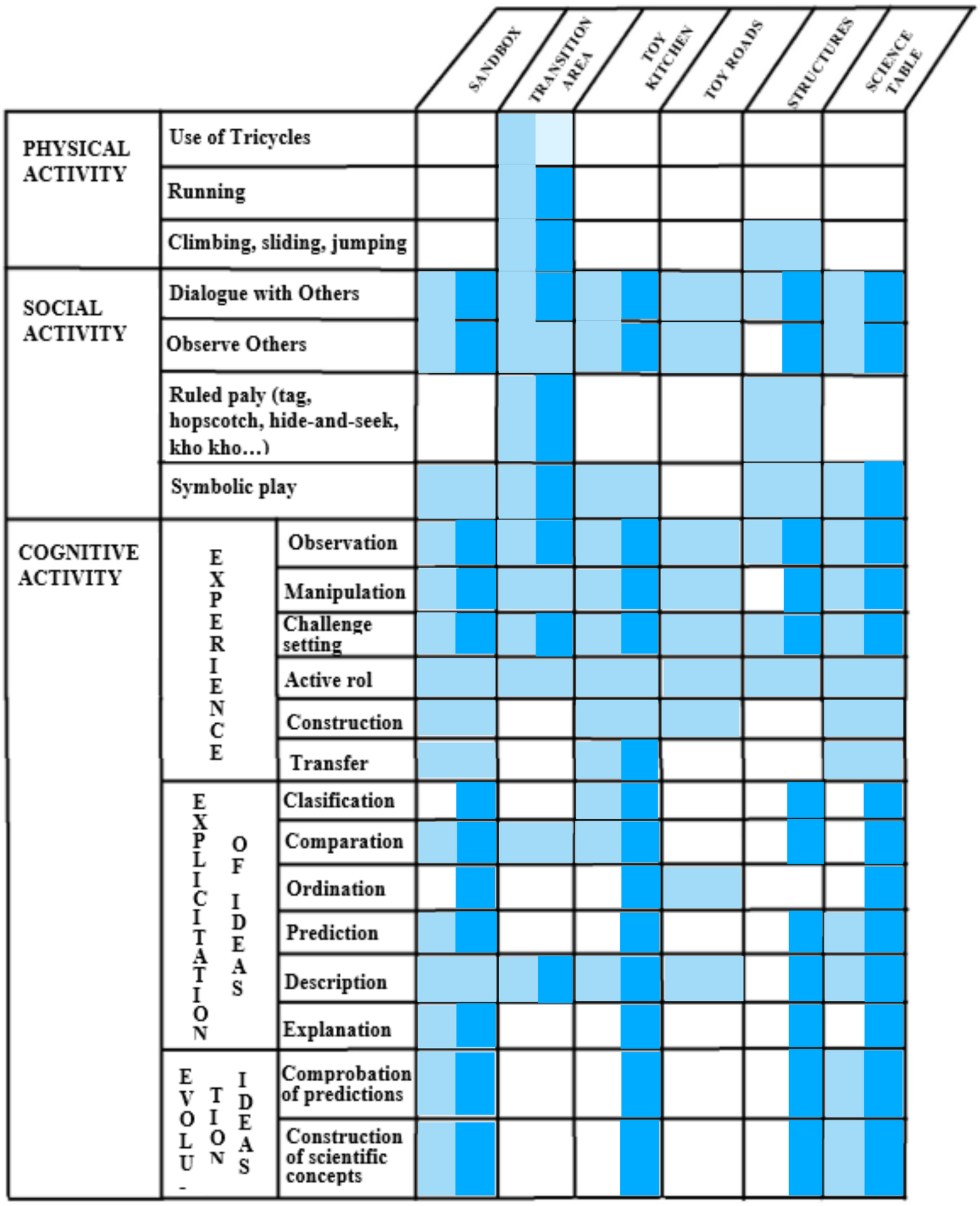
Discussion

The results of this preliminary study suggest that, although playground modifications increased overall activity and facilitated children's engagement with various scientific phenomena, physical changes alone are insufficient to ensure learning. While the modifications appeared to support children's experience with reality, activities involving explicitation and, especially, the evolution of ideas remained scarce. These latter stages are cognitively more demanding, as they require children to reflect on their experiences, make connections, and progressively transform their initial ideas. The limited presence of such activities during recess suggests that, in free-play outdoor contexts, advancing beyond direct experience towards conceptual development is unlikely to occur without intentional pedagogical support. This finding reinforces the importance of teacher scaffolding as a key element in fostering deeper forms of scientific learning, particularly when the aim is not only to provide rich experiences, but also to support meaning-making processes. In this sense, it is necessary to go beyond the design of high-quality spaces that offer meaningful experiences and accompany these experiences with pedagogical support that helps children connect evidence with scientific ideas (Gomes & Fleer, 2020; Peinado Alamillo et al., 2022).

As noted by Sanz et al. (2021), there is a tendency to over-rely on rich and stimulating environments to promote learning. In line with this observation, and echoing the reflections of one of the interviewed teachers, our findings suggest that rethinking outdoor spaces as learning environments must also involve reconsidering teachers' roles within them. The schoolyard is undoubtedly an educational space, rich in opportunities for discovery (Speldewinde, 2024).

However, recognizing its pedagogical value must go hand in hand with teaching approaches that align with this understanding.

Figure 2. Activities taking place in the different areas of the playground before (left) and after (right) the modifications.



			SANDBOX	TRANSITION AREA	TOY KITCHEN	TOY ROADS	STRUCTURES	SCIENCE TABLE
PHYSICAL ACTIVITY	Use of Tricycles			▒░				
	Running			▒█				
	Climbing, sliding, jumping			▒█			▒▒	
SOCIAL ACTIVITY	Dialogue with Others		▒█	▒█	▒█	▒▒	▒█	▒█
	Observe Others		▒█	▒▒	▒█	▒▒	□█	▒█
	Ruled paly (tag, hopscotch, hide-and-seek, kho kho...)			▒█			▒▒	
	Symbolic play		▒▒	▒█	▒▒		▒▒	▒█
COGNITIVE ACTIVITY	EXPERIENCE	Observation	▒█	▒█	▒█	▒▒	▒█	▒█
		Manipulation	▒█	▒▒	▒█	▒▒	□█	▒█
		Challenge setting	▒█	▒█	▒█	▒▒	▒█	▒█
		Active rol	▒▒	▒▒	▒▒	▒▒	▒▒	▒▒
		Construction	▒▒		▒▒	▒▒		▒▒
		Transfer	▒▒		▒█			▒▒
	EXPLICITATION OF IDEAS	Clasification	□█		▒█		□█	□█
		Comparation	▒█	▒▒	▒█		□█	□█
		Ordination	□█		□█	▒▒		□█
		Prediction	▒█		□█		□█	▒█
		Description	▒▒	▒█	▒█	▒▒	□█	▒█
		Explanation	▒█		□█		□█	□█
	EVOLU-TION IDEAS	Comprobation of predictions	▒█		□█		□█	▒█
		Construction of scientific concepts	▒█		□█		□█	▒█

The findings also point to the need to rethink what it means to teach and learn science in early childhood education. While some interviewed teachers emphasized the importance of strategies such as questioning or encouraging hypothesis formation, their descriptions of scientific learning in the schoolyard were often limited to references to specific activities or materials. This suggests a predominantly activity-oriented view of science learning, rather than one that considers concept formation. Such a perspective may help explain the limited teacher intervention observed during outdoor play. If scientific learning is understood simply as "*playing with specific materials,*" then further involvement may seem unnecessary. Similar patterns were identified by Gomes and Fleer (2020), who distinguish between activity-oriented and conceptually-oriented "sciencing attitude". Further research could explore teachers' attitudes towards science learning and how these perspectives shape their practices in outdoor spaces.

Figure 3. Activities taking place before and after the modifications.

In this sense, moving beyond the slide implies rethinking playgrounds not merely as spaces for physical activity or unstructured play, but as learning environments with genuine educational potential. While the design and naturalisation of outdoor spaces are important starting points, they are insufficient on their own. Fully realising the educational value of playgrounds requires teachers to adopt an active and reflective role, recognising when and how to intervene to support children's progression through the different stages of scientific activity. Only by combining thoughtfully designed environments with intentional pedagogical accompaniment can playgrounds become spaces where play and scientific learning meaningfully converge, thus enabling us to truly move beyond the slide.

Acknowledgement

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Measuring Motivation And Socioeconomic Status In Primary Science Learning

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Educational inequalities related to family income emerge early in primary school and affect children's performance and motivation in science, as well as their digital skills ('digital habitus'). To investigate the impact of digital gamification on the motivation and learning outcomes of children with different backgrounds, two child-appropriate instruments were developed and piloted: a motivation questionnaire based on the CAIMI scale (Gottfried, 1985) and a socioeconomic status (SES) questionnaire that relies solely on child-reported information. The adapted motivation scale demonstrated high reliability in the pilot study (α = .89). Although the reliability of the SES instrument is questionable (α = .55), it reflects the correct correlations with the occupational status of the parents and the social index of the respective school (a value used in Germany to describe a school's social composition).

Keywords: Inclusive Education, Socio-Economic Status, Primary Science Education

Framing Project

Within the framing project 'Level up! Digital Gamification in Primary Science Education. How Digital Gamification Affects Motivation and Learning Outcomes – Especially in Children from Families with a Lower Socio-Economic Status' (Wartig & Stinken-Rösner, 2023), we developed two questionnaires. One measures children's motivation for science, and another tries to determine children's socioeconomic status (SES) solely based on the information given by the children. Both instruments and their development are described in this article.

Context And Relevance To Science Education

In Germany, educational performance and success are significantly affected by family income (Wößmann et al., 2024). Furthermore, children from families with a lower income do not attend grammar school as often as their peers from higher-income families. Also, children from lower-income families often get lower grades even if the children's performance is the same as that of more well-to-do children (Maaz et al., 2011).

In addition, children from lower-income families have to deal with inferior motivation (Maaz et al., 2011) and often a lack of (non-)material resources to promote their interests, talents, or personal strengths (Solga & Dombrowski, 2009). As a result, by the end of primary school, less affluent children are up to two years behind their peers in STEM subjects (Schwippert et al., 2020, 2024). Such clear differences in STEM education cannot be ignored. Developing scientific literacy is essential for trusting scientific facts (Stekelenburg, 2026) and resisting misinformation (Osborne & Allchin, 2025). Therefore, it is a fundamental goal of the German school system (KMK, 2004) that is already relevant in primary education, forming the basis for further education (GDSU, 2013). In addition to the described issues, there are also disparities in the 'digital habitus' between children from lower- and higher-income families. While children from more privileged social backgrounds also use tablets or other digital devices for educational purposes, children from lower socioeconomic backgrounds mostly consume leisure content (Rudolph, 2019). This discrepancy in the utilization of digital media can lead to a further increase in inequality (Kutscher, 2019). Van Dijk (2017) describes these differences and their consequences as 'second-level divide’. These problems contrast with the German Ministry of Education’s goal of building a school where digital competencies are conveyed to everyone (KMK, 2015).

Aim And Methods

The framing project aims to determine what impact digital gamification has on the motivation and learning of students from socio-economically various backgrounds. Gamification hereby describes the introduction of gaming elements into non-gaming contexts (Kapp, 2012). Even though digital gamification shows a positive impact on intrinsic motivation (Xi & Hamari, 2019), it is barely used in primary science education in Germany (acatech & Joachim Herz Stiftung, 2023). The effects of digital gamification on lower-income children have not yet been explored.

This status quo serves as the foundation for our research question: What is the effect of digital gamification on the motivation and knowledge of students from a variety of social backgrounds in primary science education?

To address the research question, we are conducting an intervention study that includes an intervention group receiving a digital gamification treatment and a control group with approximately the same number of participants, drawn from different schools in North Rhine-Westphalia, a federal state of Germany.

A digital learning environment was designed for the intervention group, comprising several gamification components and accompanying hands-on activities for discovering different types of forces (Wartig & Stinken-Rösner, 2025). Gamification elements we used are collecting points, storytelling (Fischer & Reichmuth, 2020), and (direct) feedback (Kapp, 2012) given by a pedagogical agent (Clarebout & Heidig, 2012) or by visualizations (e.g. a wrong answer turns red, a right one turns green). We chose the direct feedback because it is a highly effective form of feedback (Kopp & Mandl, 2014). The control group explores the same types of forces with worksheets and hands-on activities, but without any kind of digital gamification.

To measure intrinsic motivation and the students’ knowledge about forces in the pre- and post-test, as well as the children’s SES, we needed instruments designed specifically for our target group. Intensive research showed that none of the existing instruments fit our requirements completely.

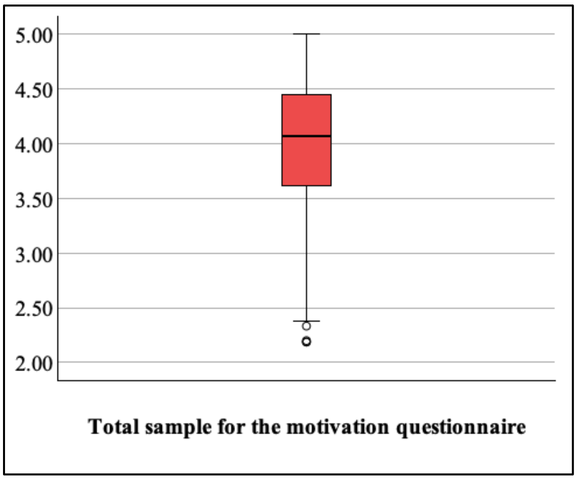
Construction Of The Motivational Instrument

To measure the children’s motivation, we developed a test based on the ‘Children Academic Intrinsic Inventory’ (CAIMI) by Adele Gottfried (1985). The CAIMI investigates the motivation of children between the ages of 8 and 13 in different school subjects and general academic motivation. We concentrated on the 24-items science scale, whose items are answered on a five-point Likert scale. Because the CAIMI is in English, we had to translate the science scale into German; we loosely followed the TRAPD approach (Harkness, 2003). In a first step, six different persons translated the CAIMI science scale into German. The translators stayed as close as possible to the original items. In a second step, we discussed which of the translated items best fit the original one. Hereby, language-specific terms were discussed, as it is recommended in the TRAPD approach. For example, one of the relevant issues was how to translate the word ‘science’. The literal German translation (Naturwissenschaften) does not match to the name of the corresponding subject (Sachunterricht) in German primary school curricula. To prevent misunderstandings, we decided to use the term ‘Sachunterricht’.

The original questionnaire includes a few negatively formulated statements (like ‘I am not curious about learning things in science.’). We reformulated these into positive statements (‘I am curious about learning things in science.’) to reduce the impact of negative items on the answering behaviour to a minimum (Stinken-Rösner & Laumann, 2023). Furthermore, especially younger children have problems with answering inverted questions (Woods, 2006). Since several items addressed the same thing (e.g., curiosity), but one was phrased positively and the other negatively, we ended up with duplicate items. Consequently, we deleted the duplicates. By doing so, we could reduce the questionnaire to 17 items. As provided in the TRAPD approach, we tested the modified instrument before using it in our main study (Harkness, 2003). The translated and adapted questionnaire achieved a Cronbach's α = .89 (N = 119 fourth graders).

This result is similar to those from the original science scale, which were .69; .90; and .91 (Gottfried, 1985). Additionally, we interviewed fourth graders who did not participate in the pilot study about the questionnaire. The conversation revealed an item that the children did not understand; respectively, the children believed the item was a further duplicate. Removing the item did not affect the instrument's reliability (α = .89, N = 119). As a result, we obtained a final questionnaire with 16 items. Furthermore, the children requested an 'I don't know' option and the option to tell the researchers their favourite primary science topic and activity. Figure 2 visualizes the results on motivation from the pilot study as a box plot.

Figure 2. The box plot illustrates the mean scores on a scale from 1 to 5, with higher values indicating a stronger level of motivation. The line within the box symbolizes the median.



Construction Of The SES Instrument

Normally, the SES of children is determined by the education, income, and occupation of the children's parents or legal guardians (Ditton & Maaz, 2011). However, this method poses the risk of a drastically reduced sample, as experience has shown that not all guardians take part in this kind of survey. The resulting challenge was to develop an instrument for the children's SES by asking only the children. For this purpose, we first analysed existing studies (for example: Andresen et al., 2020; Fishbein et al., 2024; Lenz et al., 2021; Mang et al., 2021) searching for items that give information about the SES of the participants. We categorized the items according to Bourdieu's concept of capital into the groups 'economic capital,' 'social capital,' and 'cultural capital' (Bourdieu, 1986). We identified the most frequently used items and established criteria to minimize our item pool. For example, we decided not to ask about smartphones owned by the children, because in Germany, children of primary school age often do not own a smartphone of their own for reasons other than lack of money (LFK, 2023). Additional items were developed based on recent survey results, like membership in a sports club. This question is promising because in Germany, only 40% of children from low-income families are members of a sports club, while 71% of the children from better-off backgrounds participate in sports clubs (Tempelmann et al., 2022). Furthermore, we also chose items that appear more contemporary.

All in all, we ended up with ten items. Although we know that children are not always aware of their parents' occupations (Currie et al., 1997), we included a question about it in the pilot survey. Answers were coded according to the '(Highest) International Socio-Economic Index of Occupational Status' (HISEI). The HISEI assigns numeric values to occupations based on income and educational level (Ganzeboom & Treiman, 1996; Ganzeboom, 2010) and is also used in studies like PISA (Lewalter et al., 2023).

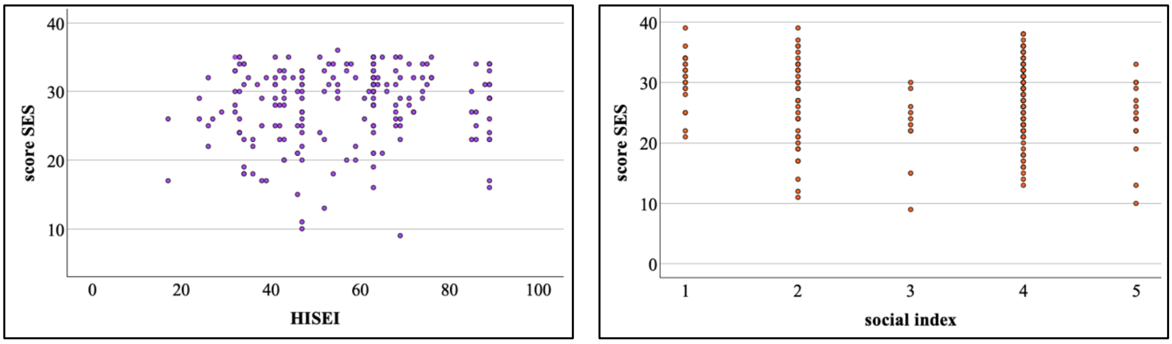
In addition, we recorded the social index of the participating schools. The social index is a value between 1 (fewer social challenges) and 9 (heavy social challenges) in North-Rhine-Westfalia (Germany) to describe the social composition of a school. The social index is based on different indicators, e.g., how many minors in the vicinity of the school receive social welfare. It can therefore be used as a rough measure of the SES of the student body, but not of individual students. Both measurements, parents' occupations and the social index of the school, are used as references to evaluate the quality of our scale.

To validate our instrument, we tested the following hypotheses:

1) The children's answers correlate positively with the parents' occupation (respectively, the corresponding HISEI).
2) The children's answers correlate negatively with the school's social index.

Piloting took place in the 'teutolab physik,' an extracurricular learning venue at Bielefeld University. After excluding one item that children constantly misunderstood, we ended up with nine final items and a questionable Cronbach's α of .55 (N = 201) for the SES-scale. However, there is a low (not significant) correlation between the SES-scale and the parents' HISEI (r = .133, p = .056; N = 207) (Figure 3, left) and a low significant negative correlation between the SES-scale and the social index of the respective schools (r = -.126, p = .032; N = 289) (Figure 3, right). For the final set of items, see Table 1 (next page).

Figure 3. Relationships Between Socioeconomic Status Indicators. *Left*: Correlation between HISEI scores and results of our SES questionnaire. *Right*: Correlation between the social index and the results of our SES questionnaire.



Discussion

The pilot study of the motivation scale shows that our questionnaire's psychometric properties are quite similar to the source questionnaire's. This indicates that our instrument can quantify the motivation of children in primary science education in Germany.

Measuring SES solely based on children's answers remains challenging. With a questionable Cronbach's α of .55, our scale does not stand out from existing instruments (cf. versions of the FAS: Corell et al., 2021; Kehoe & O'Hare, 2010). The theoretically predicted correlations between SES, parents' occupation and social index are low and only significant in the case of the social index and the SES. Even though reliability and validity are comparable to existing scales, the strength of our questionnaire is that our items are more contemporary and much closer to the children's living environment.

Table 1. Translation of the SES items. Please note that only the German version was piloted. Items 1 and 2 are answered on a four-point Likert scale from every day to never while items 3 to 9 are yes / no questions. The last question is about the parents' / legal guardians' occupation. Moreover, all items have a 'I don't know' option.

	German original item	English translation	source / reasoning
1	Wie oft liest du in deiner Freizeit Bücher oder Comics?	How often do you read books or comics in your leisure time?	Lenz et al., 2021
2	Wie oft trinkst du Limonade?	How often do you drink lemonade?	Lower-income families do not eat as much healthily as wealthier families do (Fakete et al., 2016).
3	Hast du ein Zimmer für dich allein?	Do you have a room on your own?	Bos et al., 2016; Lenz et al., 2021; Mang et al., 2021; Wagner et al., 2009
4	Gibt es bei dir zu Hause Musikinstrumente?	Do you have any musical instruments at home?	Mang et al., 2021
5	Hat deine Familie einen Rasenmäher oder einen Rasenmähroboter?	Does your family have a lawn mower or a robotic lawn mower?	Beese et al., 2022; Schaufelberger et al., 2024
6	Gehst du in einen Sportverein?	Do you belong to a sports club?	Beese et al., 2022
7	Gehst du mit deiner Familie ins Theater, Kino oder ins Museum?	Do you go to the theater, cinema, or museum with your family?	Beese et al., 2022; Holz, 2006
8	Warst du letztes Jahr mindestens eine Woche im Urlaub?	Did you go on vacation for at least one week last year?	Andresen et al., 2020; Beese et al., 2022
9	Lesen deine Eltern Bücher?	Do your parents read books?	Solga & Heisig, 2015.
10	Welche Berufe haben deine Eltern?	What do your parents do for a living?	Mang et al., 2021

Furthermore, based on our data, we see the necessity to critically discuss the use of measures like the social index. Both the social index and parents' occupation are commonly used as predictors for the children's SES in Germany. Because of the opposite polarity in their definition, it is assumed that the HISEI and the social index correlate negatively. However, our results differ from this expectation ($r_{\text{occupation and social index}} = .006$; $p = .940$; $N = 160$), as no correlation could be proven. This contrasting outcome should be investigated further, as it may indicate that a school's social index reflects its actual student body only to a limited extent, even when the school is viewed as a whole. One possible explanation for this conflict is that although the social index uses data on the proportion of children in the local area who receive social benefits, it does not consider the proportion of benefit recipients who attend the school (Schräpler & Jeworutzki, 2021).

Outlook

Data collection of the main study is currently being completed. The final number of participants is satisfactory, but we encountered the problem that mainly schools with an average social index participated in our study. In the final step, we will compare the effect of digital gamification on content knowledge gain and motivation for groups with varying SES.

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Learning Science Through Multimodal Representations

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There is growing agreement that guided inquiry and multimodal representations support students' meaning making in science. Grounded in Lemke's social-semiotic perspective and sociocultural views on collective sense-making, this study employs a case study approach across three year 5 classes in a Fijian primary school. Data was collected through learning space observations and Talanoa, a culturally appropriate qualitative data collection approach and methodology in Pacific contexts. Data was thematically analysed with findings showing that multimodal representations enhanced students' cognitive engagement by contextualising their learning of scientific concepts. Data highlighted improved affective engagement through the use of culturally relevant representations. Furthermore, Talanoa showed that sharing stories and reflecting collaboratively with peers deepened students' understanding of science concepts. The findings also revealed the key role that teachers play in scaffolding the meaning making process. These findings provide valuable insights for science educators into leveraging multimodal and culturally relevant strategies to enhance students' meaning making in scientific activities.

Keywords: Multimodal representations, Science, Engagement, Talanoa

Introduction

There is growing research interest in the meaning making process of science activities and concepts and the use of multimodal representations that support learners. Multimodal is defined as "the practice in science discourse of coordinating different modes to represent complex claims and evidence, where textual, mathematical and visual modes are integrated to explain and justify findings" (Waldrip & Prain, 2013, p. 15). In this study, the term 'multimodal' will be used to refer to a combination of more than one mode in representing scientific concepts. There is now evidence that encouraging all learners of science to generate their own representations to demonstrate their knowledge and understandings, construct a logical scientific argument and show the reasoning that they have used to arrive at a particular conclusion (Chand, 2019; Greeno & Hall, 1997; Waldrip & Prain, 2011).

The study is guided by a social semiotic perspective of multimodal representation to enhance meaning making (diSessa, 2004; Lemke, 2003) and socio-cultural theory (Vygotsky, 1978). Researchers are in consensus that learning outcomes of science learners improve with the integration of multimodal representations (Andersen & Munksby, 2018; Tytler et al., 2013).

The authors highlight the importance of multimodal and culturally responsive pedagogies in science to better support all learners, recognising that much of the current scholarly literature on the use of multimodal representations, have been pursued mainly in developed, western settings. The need to establish culturally appropriate practices when exploring student and teachers' knowledge and understandings of science concepts is critical. This study is informed by the Talanoa methodology (Vaioleti, 2006) to seek answers to the questions:

The paper examines the use of multimodality in the meaning making process in science by answering the questions:

1. How does the use of multimodal teaching strategies influence student engagement?

2. What role do the teachers play in creating and making sense of multimodal representations?

Methodology

This study is based within a qualitative research paradigm, using a case study approach to examine the impact of multimodal representations had on the students in year 5 at a primary school in Fiji. Qualitative methods were employed for this research to capture the use of multi-modal representation in the participants' setting (Punch, 2013). Data was collected through learning space observation and Talanoa.

Talanoa is rooted in oral communication and recognised in many Pacific Island countries such as Samoa, Tonga and Fiji (Nabobo-Baba, 2006; Otunuku, 2011; Prescott, 2008). Talanoa is also considered a way to engage in dialogue or tell stories (Halapua, 2008). In this study, Talanoa was conducted with intentional openness to listen to participants' experiences (Farrelly & Nabobo-Baba, 2014) which enabled the researcher to become part of the family to listen and find solutions to the phenomena being studied.

The study involved three year 5 teachers at a Fijian urban primary school. All teachers had over 10 years of experience. The class teachers from the case study class were invited for Talanoa after the learning space observation. Chosen class represented students from diverse cultural backgrounds. From each of the three classes, 10 students ages 9-10 participated in the research.

This study did not involve intervention. The teachers of the chosen classes planned and devised an instructional context in which students' conceptual understanding and reasoning were to be challenged. During the sequence of lessons, the researcher's role was mostly that of a participatory observer. Before the study began, the first researcher acted as an observer in the class for a few lessons to familiarise herself with the operation of the class and build respect and gain the acceptance and trust of students and the teacher (Farrelly & Nabobo-Baba, 2014).

The learning activities required the students to consider possible reasons for increased flooding in Fiji in recent years. The design of the activity assimilated concepts and skills from other areas of the curriculum, notably Society and Economic Development classes (Ministry of Education Heritage and Arts, 2013), to allow students to investigate the events in relation to their own people, culture, resources and environment. As part of the instruction, the class teachers introduced a picture of flooding from a daily newspaper and facilitated the students' focus on the picture to develop a question relating to the flooding phenomena which they would like to explore. Students were asked to interpret the phenomena collaboratively and represent their understandings multimodally through using drawings with written and verbal explanations.

Ten participating students, representing each of the two collaborative groups, were invited to engage in a 30-minute Talanoa session to expand and reflect on the learning experience from the student perspective. These students were selected based on the consent provided. A further three class teachers who had previously taught the lessons observed were invited to participate in a 40–60 minute Talanoa session focusing on pedagogical decision-making and the instructional strategies employed throughout the teaching experience.

The analytic process of Talanoa transcripts and field notes from the learning space observation drew on inductive thematic analysis as outlined by Braun and Clarke (2006). This involved multiple close readings of transcripts, the creation of preliminary codes, and the iterative refinement of patterns across the dataset. Particular attention was paid to culturally embedded language and the contextual meanings conveyed during Talanoa and subsequent verification discussions, supporting accurate interpretation of culturally specific expressions and concepts (Vaioleti, 2006).

Trustworthiness of the data was enhanced through collaborative analysis by Researchers One and Three, both of whom identify as Pacific People and possess contextual and cultural knowledge relevant to the study. This shared positionality supported culturally informed interpretation and enabled systematic cross-checking of themes and insights. Such collaborative sense-making helped to minimise the influence of individual subjectivity and strengthened the credibility of the findings. Throughout the analysis, the focus remained firmly aligned with the research questions by exploring the ways teachers articulated cultural knowledge as: (1) How does the use of multimodal teaching strategies influence student engagement? and (2) What role do the teachers play in creating and making sense of multimodal representations?

Findings

The study identified that teachers' planning was prescribed by the curriculum with little emphasis on the use of varied representational modes in their learning spaces. However, actual teaching provided intentional opportunities for students to display their conceptual understanding through multiple modes.

The findings of this study indicate that the use of multimodal teaching strategies positively influenced students’ engagement in science learning, while teachers played a central role in designing, modelling, and scaffolding multimodal representations to support meaning-making. When students were provided with space and opportunities to represent their understanding through multiple modes such as drawings, diagrams, charts, written text, and Talanoa demonstrated increased engagement.

Teachers reported that multimodal approaches generated excitement and enthusiasm among students, particularly when culturally familiar modes were incorporated into science learning. There was a high level of affective engagement. Students expressed enjoyment and a sense of pride when constructing drawings and charts, and when sharing their ideas through Talanoa. One student stated, “I always feel good when we are asked to draw and share our stories (S10) while another commented, “we prepare charts and do drawings, it’s fun” (S6). Teachers similarly observed that students were highly motivated during multimodal activities, noting that students wanted to create their best work and were more willing to participate when drawing and discussion were included (T1).

In addition to affective engagement, multimodal teaching strategies support deeper cognitive engagement. Teachers shared that students were better able to reason, critique their learning, and explain scientific concepts when they used different modes of representation to learn and present their understanding. The construction of representations allowed students to break down complex phenomena into more manageable components, which supported analysis and synthesis of information. Teachers facilitated this process by guiding students to represent scientific ideas through structured approaches “using separate diagrams to illustrate causes, effects, and solutions related to phenomena like flooding” (T3). This approach supported students in organising their thinking and developing clearer explanations. Student evidence further demonstrated increased conceptual understanding and scientific language use, with students sharing that they had “learnt new scientific terms and could now explain the concept of flooding and its impacts on their people” (S7). The emotional story associated with flooding was also shared during Talanoa with both participating students and teachers.

Engagement was also enhanced through multimodal strategies, particularly through the use of Talanoa as a communicative practice. Teachers reported that students were more engaged and confident when sharing their learning through Talanoa (T1), as it created a safe and familiar space for discussion (T2). Through these interactions, students collaboratively shared personal stories, listened to their peers, and made connections between lived experiences and scientific concepts. As evidenced from the findings, students enjoyed engaging collaboratively in learning and sharing their understanding, "I like creating drawings with others" (S8) and having Talanoa in our science class" (S5). The findings showed that Talanoa supported deeper discussions, allowing students to collaboratively construct understanding and relate scientific ideas to other phenomena and contexts.

Teachers played a crucial role in enabling students to engage meaningfully with multimodal representations. Although teachers indicated that lesson planning was often driven by curriculum requirements with a stronger focus on content coverage than on representational modes, they made intentional decisions during instructions to integrate multimodal representations. Teachers described selecting representational modes responsively based on the learning context, "the phenomenon being explored, and the students present in the classroom" (T1). Some teachers deliberately aligned task outcomes with particular representations and considered cultural appropriateness when choosing modes, noting that "drawing, Talanoa, and storytelling were especially effective for engaging students" (T2).

Teachers also acted as expert models by demonstrating how different representations could be constructed and explaining why specific modes were appropriate for sharing meaning. It was evident that modelling the use of diagrams, labels, gestures and written texts was beneficial to the students. Teachers helped students understand how representations functioned as tools for scientific communication (T3). Alongside modelling, teachers scaffolded students' representational skill through explicit instruction, questioning, and gradual release of responsibility as students engaged in representation contraction. Teachers shared that "students were initially provided with clear guidance on which representations to use" (T1), and as they developed confidence, they were encouraged to explore additional modes independently.

Culturally responsive practices were a prominent feature of teachers' approaches to multimodal teaching. Teachers recognised drawing and Talanoa as culturally embedded practices and intentionally incorporated them into science lessons. One teacher described "drawing and design-making as cultural skills" (T4), while Talanoa was identified as a "practice grounded in cultural values and commonly used to share experiences and ideas" (T3). By allowing the use of these practices within science learning, teachers supported students to engage more confidently and meaningfully with scientific concepts while maintaining strong connections to their cultural identities.

Overall, the findings demonstrate that multimodal teaching strategies enhance student engagement by fostering enjoyment, supporting deeper thinking, and encouraging collaborative learning. Teachers played a key role in shaping these outcomes through their responsive planning, modelling of expert representations, scaffolding of students' meaning making, and integration of culturally meaningful modes of communication. These practices collectively supported students to use multimodal representations as effective tools for understanding and communicating scientific ideas.

Discussion And Implications

The findings of this study demonstrate that multimodal teaching strategies enhance student engagement and support meaningful science learning when they are used appropriately in science learning. Although teachers' planning was largely prescribed by curriculum requirements, pedagogical decisions and reasoning created opportunities for students to express understanding through drawings, diagrams, charts, written texts, verbal explanations and Talanoa. This aligns with research which positions science learning as inherently multimodal, where meaning is constructed through the coordination of visual representations such as drawings, verbal, and gestural representations (Chand, 2019; Jewitt et al., 2016; Ainsworth, 2006). Providing multimodal representations enabled students to engage effectively, as evidenced by enjoyment, enthusiasm, and work completion, a factor strongly associated with sustained engagement in learning (Fredricks et al., 2004).

The findings also indicate that multimodal practices supported deeper cognitive engagement. Students' construction of drawings and diagrams allowed them to break down complex phenomena, organise relationships between elements of the task, and articulate explanations more clearly. Such reasoning processes are central to scientific meaning-making and are strengthened when students actively construct and refine representations rather than simply receiving information (Tytler et al., 2013; Cirkony et al., 2022). Decisions regarding what to include, how to organise components, and how relationships are shown represent important sites of conceptual development.

The findings extend our understanding of the use of multimodal representations and integration of Talanoa as a culturally responsive mode. The use of Talanoa as an informal conversation through which students shared their stories and relating it to their context was effective. It enabled students to unlock the richness of experience and knowledge embedded in a socio-cultural environment (Halapua, 2008). On the one hand, Talanoa gave insight of students' understanding and reasoning of science concepts, while on the other hand, it captured the emotions associated with the phenomenon being studied. We suggest that scientific terms be introduced slowly while engaging in Talanoa to link scientific concepts to real life situations.

The findings indicate that affective and cognitive engagement of students improved with the use of multimodal and culturally relevant representations. Findings indicated that students showed an increased level of interest in exploring the given phenomenon. Drawing and Talanoa were the most common representations used, indicating the cultural connection these modes have with the context of the study. The construction of appropriate and logical diagrams, the inclusion and placement of components, showed the students' ability to convey their mental representations on each drawing. This aligns with Tytler et al. (2013) who asserted that reasoning happens when students make representational selections and decide appropriate size or how to put different components together, hence improving the meaning making process.

A key implication of these findings is the central role of teacher expertise in designing, modelling, and scaffolding multimodal representations. Teachers functioned as expert guides, modelling how representations operate as scientific tools and supporting the meaning making process for students. This highlights the importance of teacher professional learning that moves beyond content coverage to include representational pedagogy. Supporting teachers to intentionally plan for multimodality as well as choosing culturally appropriate representations can strengthen student engagement and conceptual understanding.

Conclusion

This study identifies and analyses the processes through which primary school students strengthen their conceptual understanding and scientific reasoning. It is evident that multimodal representations, including those with cultural connectedness, have a positive impact on students' cognitive and affective engagement. While the authors acknowledge the small sample size of students involved in the learning space observations limits the generalisability of the findings, this research highlights the broader question of the need to consider culturally sensitive forms of expression as part of the overall conception of a learning environment designed to elicit student thinking. Valuing diverse modes of knowledge representation in science can enhance Indigenous learners' engagement, understanding, and cultural affirmation (Chand, 2019).

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Designing Video-Tutorials As A Supporting Tool In The Experimentation Process

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Interactive video-tutorials represent a promising tool for enhancing science education by supporting learners in acquiring procedural competences critical for scientific literacy. Unlike traditional explanatory videos, interactive video-tutorials are action-guiding in nature, providing step-by-step instructions to help students replicate actions and engage in hands-on scientific practices. This study focuses on identifying design criteria for effective interactive video-tutorials that support learners in the proper use of measuring devices, such as thermometers, scales, stopwatches, and rulers, during experimental processes.

Using Kulgemeyer's (2020) framework for effective explanatory videos as a foundation, this research adapts and extends the criteria to meet the specific demands of interactive video-tutorials. To achieve this, the criteria were critically reviewed for their applicability to action-guiding content and adjustments were made to address the unique challenges of designing interactive video-tutorials for primary learners. These include emphasising clarity, coherence, age-appropriate content, and accessible language, while maintaining the authenticity of the experimentation process.

The results demonstrate how interactive video-tutorials should be designed to integrate digital media into hands-on learning, enabling learners to actively engage in measuring processes in experimental contexts and develop critical skills. These tools offer a means of bridging the gap between digital resources and authentic scientific practices in primary education. Future research will explore the effectiveness of interactive video-tutorials that follow the identified design criteria across educational contexts and their potential to foster independence in experimental tasks, contributing to the development of innovative strategies for science education.

Keywords: Digital Learning, Instructional Design, Primary Science Education

Introduction

The acquisition of scientific competences is central to fostering scientific literacy, a key goal of science education. Scientific literacy not only forms the foundation for individual personal development but also equips learners with the knowledge necessary to participate actively in society. To foster scientific literacy, it is essential to identify the competences learners must develop and to explore how these can be effectively enhanced within school contexts. The OECD's definition of scientific literacy, as outlined in the PISA (2018) framework, further underscores this by categorising it into content knowledge, procedural knowledge, and epistemic knowledge. While content knowledge focuses on factual and conceptual understanding, and epistemic knowledge on the processes behind acquiring scientific knowledge, procedural knowledge encompasses the practices of science (*PISA for Development Assessment and Analytical Framework*, 2018). To foster these competences, students must engage in authentic learning environments and participate actively in scientific practices, such as conducting experiments. This highlights the critical role of experiments in science education (Osborne, 2014).

However, despite their critical role, experimental activities can pose considerable barriers for learners, including methodological, communicative, and cognitive demands (Stinken-Rösner et al., 2023). The integration of digital tools has the potential to overcome barriers and to support these experimental practices in learning settings, provided they maintain the authenticity of the experimentation process.

As digital media become increasingly integral to educational contexts, explanatory videos have gained prominence as tools to support learning (Kulgemeyer & Wittwer, 2023). While explanatory videos are commonly used in schools to support the acquisition of content knowledge, they are primarily designed for passive viewing (Wolf, 2015), making them less suited to fostering procedural competences that require active engagement. In contrast, video-tutorials, with their action-guiding character (Wolf, 2015), offer step-by-step instructions that could encourage learners to imitate demonstrated actions. This unique characteristic positions video-tutorials as a promising digital tool for supporting the development of procedural skills, such as handling measurement devices, recording data, and conducting experiments independently. Building on this approach, interactive video-tutorials extend traditional formats by integrating learner-controlled decision points that actively involve the viewers during the experimentation process. Rather than following a fixed linear sequence, learners can interact with interactive video-tutorials to access support that is relevant to their current task. These forms of interactivity are assumed to support active and self-regulated engagement, which is considered essential for the acquisition of procedural knowledge in experimental contexts (Chi & Wiley, 2014). By bridging the gap between digital resources and hands-on learning, interactive video-tutorials can provide an innovative way to engage students in scientific practices and enhance their experimental competences.

The importance of investigating the use of interactive video-tutorials is twofold. First, the increasing integration of digital media into classrooms requires a deeper understanding of how to design and implement these tools effectively. Second, at primary school level, where the foundation for scientific literacy is established, fostering the acquisition of scientific competences, especially procedural ones, through innovative methods is paramount. Despite the potential of interactive video-tutorials to support experimentation, their application in primary education remains unexplored. This research aims to address this gap, focusing on the systematic identification of design criteria for interactive video-tutorials to promote scientific competences at the primary level. These design criteria are theoretically derived and defined based on established frameworks for instructional design, multimedia learning, and research on experimental and measuring competences.

Theoretical Framework

The use of digital media, especially media such as explanatory videos, plays a central role both in everyday lives of students and in school contexts. With regard to teaching contexts, there are numerous possible applications, such as in flipped classroom settings or the production of videos by students as a presentation tool. It can be assumed that the relevance of explanatory videos for science lessons will increase in the future (Kulgemeyer, 2020).

Explanatory videos are typically defined as self-produced short films designed to explain complex concepts. However, in contrast to these classic explanatory videos, (interactive) video-tutorials are instructional in nature. Their defining characteristic is their action-guiding purpose, offering step-by-step instructions that encourage viewers to replicate the demonstrated actions (Wolf, 2015). While explanatory videos have been extensively researched, the potential of (interactive) video-tutorials as a medium to support hands-on-activities in science education remains unexplored. Interactive video-tutorials are particularly well-suited to contexts that require hands-on-activities, such as scientific experimentation, as they allow learners to access procedural guidance in close temporal and functional proximity to their own actions. Experiments are a cornerstone of science education and involve numerous practical steps, requiring students to develop various experimental competences (Tesch & Duit, 2004). Experimental processes can be categorised into three overarching phases: planning, performing, and evaluating experiments, each of them requiring specific competences (Schreiber et al., 2009). Supporting the acquisition of these competences requires instructional formats that can be flexibly aligned with different phases of the experimentation process and with learners' situational needs. Interactive video-tutorials on the use of measuring devices appear to be particularly suitable, as they address competences that are independent of the individual experiment. Also, learners at the primary school level are faced with the challenge of not only familiarising themselves with relevant measuring devices and the respective quantities and units, but also having to apply them for the first time in experimental settings to differentiate subjective sensory impressions from objectively measured physical quantities (GDSU, 2013).

In the context of experimental learning, instructional support needs to be closely aligned with the procedural structure of the measuring process. Learners are required to make decisions and perform actions at the different stages of measurements to foster sub-competences. Accordingly, instructional approaches aimed at experimental competences should allow learners to access guidance that corresponds to their current phase within this process. However, the effectiveness of interactive video-tutorials, just like that of explanatory videos, depends heavily on their design. To ensure they support learning effectively, they must adhere to key instructional design principles (Kulgemeyer & Wittwer, 2023) and integrate seamlessly into the broader learning process.

Aims And Research Questions

The research presented focuses on identifying design criteria for interactive video-tutorials that effectively support learners in using measuring devices during experimental processes. The overarching aim is to explore how these interactive video-tutorials can best facilitate the development of experimentation competences, with a particular emphasis on guiding students through the proper choosing and handling of measuring devices as well as accurate data acquisition. We address the following research question:

What design criteria are essential for creating interactive video-tutorials that support the handling of measurement devices in experimental contexts?

Methods And Relevant Research Literature

The study employed a deductive research approach, drawing on established research literature on instructional video design as well as on models of experimental and measuring competences. On this basis, both relevant measuring-related sub-competences and design criteria for interactive video-tutorials were systematically derived and defined. The focus was placed on relating the structural characteristics of measuring processes in experimental contexts to suitable instructional design criteria for interactive video-tutorials.

Research literature on experimental competences was analysed in order to conceptualise experiments as a structured scientific practice comprising the phases of planning, performing, and evaluating experiments (Nawrath et al., 2011; Schreiber et al., 2009). These models provide a process-oriented framework that describes the sequence and structure of experimental processes in science education as well as certain experimental competences within each phase. Building on these models, measuring processes were conceptualised as a central scientific practice that occurs within all three phases of the experimentation process (Murer et al., 2025). This analysis informed the alignment of the interactive video-tutorials with relevant decision points and actions that learners need to successfully select measuring devices, read and record measured values, and represent data correctly.

Kulgemeyer's (2020) framework for effective explanatory videos informed the identification of design criteria, particularly in relation to structuring and tailoring interactive video-tutorials to support the named measuring competences throughout the three overarching phases of the experimentation process. It is grounded in principles derived from empirical research on instructional explanations and findings about multimedia learning. The concluding framework outlines 14 key criteria to guide the production of explanatory videos that are both scientifically accurate and pedagogically effective. These criteria fall into seven main categories: structure, adaption, tools for adaption, minimal explanation, highlighting relevancy, follow-up learning tasks and new, complex principles (Kulgemeyer, 2020). All criteria were critically analysed with regard to a possible implementation for interactive video-tutorials that support the handling of measuring devices in experimental contexts. Particular attention must be paid to the extent to which the criteria can be adapted to learner-controlled, non-linear digital learning formats such as interactive video-tutorials that allow for situational access to instructional support.

Bringing together both perspectives, measuring related competences and instructional design criteria were systematically related to each other in order to inform the design of interactive video-tutorials that are aligned with the measuring process and tailored to the demands of measuring activities in primary science education.

Results

Table 1 specifies measuring related sub-competences within the model of experimentation in primary school settings.

Table 1. Measuring Sub-Competences in the experimentation process in primary school settings.

Measuring Sub-Competences	Planning	Performing	Evaluating
SC1: Learners know measuring devices and can name them.	✓	×	×
SC2: Learners indicate which measuring device to use to measure different quantities.	✓	×	x
SC3: Leaners know corresponding units for quantities and can name them.	✓	×	✓
SC4: Learners select suitable measuring devices in specific experimental situations.	✓	✓	×
SC5: Learners select suitable measuring devices with regard to the measuring range.	✓	✓	×
SC6: Learners correctly read measured values from different measuring devices for the same quantity.	×	✓	×
SC7: Learners correctly read measured values while taking a parallax error into account.	×	✓	×
SC8: Learners document the measured values taken.	×	✓	×
SC9: Learners correctly transfer measured/documented values into a table.	×	×	✓

In the phase of planning, learners must decide which measuring device is suitable for the measuring process based on their knowledge about measuring devices, quantities and units. While performing the experiment, learners must correctly use each measuring device as well as correctly read and document measured values. For transparency and traceability, the documented values must then be visualised in a table during the evaluation phase (Reuter & Stinken-Rösner, submitted).

Table 2 shows the extent to which the criteria for effective explanatory videos (Kulgemeyer, 2020) can be applied to the creation of interactive video-tutorials to fit their action-guided purpose as well as our target group (primary school children).

Table 2. Implications for the design of the interactive video-tutorials based on video criteria (Kulgemeyer, 2020).

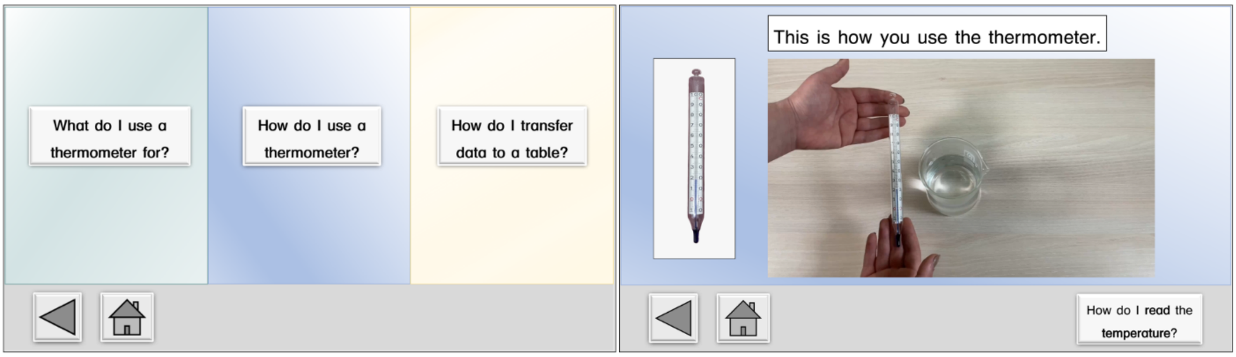
Factors	**Feature**	**Implications for interactive video-tutorials**
Structure	Rule-example/example-rule	Interactive video-tutorials follow the example-rule structure by first demonstrating its use on a selected measuring device and then deriving general rules.
	Summarising	Interactive video-tutorials are divided into individual sections for clarity, making a summary about the whole process redundant.
Adaption	Adaption to prior knowledge, misconceptions and interest	Interactive video-tutorials focus on familiar devices and quantities (mass, time, length, temperature) and address typical handling errors.
Tools for adaption	Examples	Interactive video-tutorials show standard devices (e.g., digital and analogue scales) for each measurement type.
	Analogies and models	Not necessary with regard to interactive video-tutorials.
	Representation forms and demonstration	Interactive video-tutorials demonstrate exact procedures for using each device.
	Level of language	Interactive video-tutorials use simple, familiar professional language, avoiding unnecessary terms.
	Level of mathematisation	Interactive video-tutorials focus is on familiar units (e.g., kg, °C) and numbers ranges for clarity.
Minimal explanation	Avoiding digressions	Interactive video-tutorials focus strictly on core tasks (e.g., handling of specific measuring devices).
	High coherence	Interactive video-tutorials for each measurement device follow the same structure.
Highlighting relevancy	Highlighting relevancy	Viewing is optional; learners decide which interactive video-tutorials they need and are therefore relevant.
	Direct addressing	Interactive video-tutorials use the second person singular.
Follow-up learning tasks	Follow-up learning tasks	Hands-on activities are the motivation for using interactive video-tutorials, eliminating the need for separate follow-up tasks.
New, complex principles	New, complex principle	Interactive video-tutorials introduce new measurement actions rather than new principles.

In interactive video-tutorials, the example-rule structure comes naturally, as they demonstrate individual steps of the measurement process. Similarly, demonstrations and direct addressing are inherent to the tutorial format.

Certain criteria, like summarising and follow-up learning tasks, are unnecessary. The interactive video-tutorials are divided into clear steps, according to relevant actions in the measuring process, making summaries redundant, and hands-on activities are the actual starting point for utilisation. Other criteria require specification. Tools for adaption focus on familiar devices, accessible language, and appropriate mathematisation to match learners' prior knowledge. Coherence is ensured by following an idealised measuring process as well as using the same structure for multiple tutorials. Rather than introducing new principles, the interactive video-tutorials teach new actions in order to foster measuring competences.

The resulting criteria were used to design an interactive video-tutorial for relevant measurement devices at primary school level to measure length, time, mass, and temperature. Exemplary screenshots for the use of thermometers in the measurement process are shown in Figure 1.

Figure 1. Exemplary screenshots from the interactive video-tutorials.



This is how you use the thermometer.

When starting the measuring process, viewers must first decide which is the suitable measuring device for the quantity to be measured. For example, a thermometer should be selected for temperature measurements. In the shown example (see Figure 1, left), viewers can choose between three options: To obtain information on what a thermometer can be used for (planning), information on how to use a thermometer (performing) or how to transfer collected data to a table (evaluating). This directly aligns with the three overarching phases of the measuring process. Within these sections, further decisions aligned to the sub-competences can be made. In the planning phase (option "What do I use a thermometer for?"), learners are presented with different types of thermometers to support their decision on which instrument is suitable for a specific measuring situation and measuring range. Once a suitable thermometer has been selected, the interactive video-tutorial continues with thermometer-specific guidance. Learners can watch a short video sequence on the use of a thermometer in an exemplary measuring situation and then continue on how to correctly read the temperature (see Figure 1, right).

Outlook

The interactive video-tutorials developed in this project constitute a first step towards supporting measuring-related competences in primary science education. The next phase of research focuses on embedding the interactive video-tutorials into an experimental learning environment on sensory illusions. These provide authentic and motivating experimental situations in which learners are required to measure physical quantities in order to contrast subjective sensory impressions with objective, measured data. Within this setting, the interactive video-tutorials are integrated as a situational support that learners access during the phases of the measuring process. To investigate the effectiveness of the interactive video-tutorials, a pre-post study design is employed using a competency test targeting the named measuring sub-competences (Reuter &

Stinken-Rösner, submitted). This design allows for the systematic analysis of learners' competence development and provides insights into how interactive video-tutorials can contribute to fostering procedural competences in primary science education. The first empirical studies are planned for 2026.

Conclusions

This study highlights the potential of interactive video-tutorials as a valuable tool for enhancing science education, particularly at the primary school level. Unlike traditional explanatory videos, interactive video-tutorials are action-guiding in nature, providing step-by-step instructions that enable learners to replicate actions and acquire essential procedural skills. Given the importance of experiments in fostering scientific literacy, the integration of well-designed interactive video-tutorials could support learners in developing measuring competences while leveraging digital media to promote authentic scientific learning. By adhering to well-defined design criteria, these tools have the potential to enhance student engagement and foster the acquisition of vital experimental skills.

Using Kulgemeyer's (2020) framework for effective explanatory videos as a foundation, this study adapted and extended the criteria to address the specific challenges of designing action-guiding tutorials. Additionally, the interactive video-tutorials focus on age-appropriate measuring devices and accessible language to ensure clarity and usability and to adapt to prior knowledge. The application of these criteria was demonstrated through the development of an interactive video-tutorial for common measuring devices such as thermometers, scales, stopwatches, and rulers. By addressing specific steps in the measuring process, such as selecting, operating, and documenting with these devices, the interactive video-tutorial provides targeted support for learners, helping them to acquire procedural knowledge and improve their measuring competences.

Future research will focus on evaluating the effectiveness of interactive video-tutorials in diverse educational contexts, particularly their impact on learners' procedural competences and their ability to foster independence in experimental tasks.

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Creativity and Programming Essentials as Skills for a Transitioning Digital World

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In a fast-paced technological world, children need to be equipped with skills that allow them to keep that pace and to act accordingly. Therefore, a basic understanding in technology as well as creativity might be helpful. This enables children to find their way in a digital world that is developing at a very fast pace and also to draw on their own expertise and creative solutions to problems. It is advisable to address these skills in elementary school and lay the necessary basics here.

This study therefore examines the question of how creative and algorithmic thinking are connected. In addition, an attempt was made to develop a creative learning unit to train basic programming skills. As a basis for addressing this topic, a suitable test instrument was designed and evaluated to assess the creativity of elementary school children in the context of a learning unit on programming.

The results show that the test instrument for creativity was successfully evaluated. The results revealed that the elementary school children surveyed had almost no prior knowledge with respect to programming skills, but these skills improved significantly with the learning unit proposed in the present study.

Keywords: Computational Thinking; Early Science Education; Play and Science Learning

Introduction

In a fast-developing, increasingly digital world, a fundamental understanding of digitality and the associated processes are essential. This includes a basic understanding of the fundamental functionality of programming and the ability to think creatively and develop innovative approaches and problem-solving strategies. Creativity is described as a 21st-century skill for good reason, especially in the context of unpredictable new challenges. At this point, the question rightly arises as to where and how such skills can be examined and developed. Following the results of the latest PISA study from 2022, the consortium is also calling for creativity to be promoted in schools (Diedrich et al., 2024). Particularly in natural science and social science education in elementary school, there is seen to be special potential for creative educational processes (Holzapfel et al., 2022; Rau-Patschke et al., 2024). Further the results of the International Computer and Information Literacy Study (ICILS) from 2023 show a lack of both – computer and information literacy skills at higher proficiency levels, including operationalizing solutions (Fraillon, 2024). Digital learning environments open up a wide range of opportunities to challenge and support children technologically and in developing IT skills, as well as in the ability to think creatively and generate innovative ideas.

Agreeing with the Informatics for All Coalition that computer science education should start in elementary school (Caspersen et al., 2018), we designed a learning setting that combines creativity and computational thinking skills in elementary school.

Theoretical Framework

In the study presented here, both aspects are combined in an intervention for creative programming for elementary school children that is tested and evaluated. Now that an initial small feasibility study has been carried out and the project has been confirmed (Holzapfel et al., 2024), the focus will be on the relations between the two constructs of programming experience and creativity. Therefore, both aspects will be discussed theoretically below.

Computer Science As An Essential Skill For An Innovative World

Computer science and creativity are closely linked. Modeling activities, for example, require and simultaneously promote the application of creativity (Schubert & Schwill, 2011). Through computer science ways of thinking, working and acting, one's own ideas become functional programs, games or entire interactive systems that take on a perceptible form. The promotion of creativity in computer science lessons is therefore an important goal which can also be transferred to the technical perspective of science education in elementary school (Hubwieser, 2007). Learning environments therefore open up a wide range of opportunities to challenge and encourage children both technologically and creatively. Robot-assisted settings in particular combine creative, reflective, and technical requirements, allowing creative thinking to be immediately visible in action.

Robotic learning environments promote technical, creative, and social learning in combination (Bers, 2008). They follow the principle of technological fluency—that is the ability to use technologies creatively and purposefully, like a language. Programming skills expand children's expressive possibilities: sensors, movement patterns, and audiovisual elements can be embedded in self-selected themes and narratives. Tactile systems such as BlueBots enable intuitive, action-oriented access in the sense of "hands-on" pedagogy (Bers, 2008, p. 48). Digital storytelling with robots for example combines technology, language, and individual design. Children program robots, assign them roles, and stage stories—an expression of digital creativity (Bers, 2008; Sawyer & Henriksen, 2024).

Creatively Facing New Challenges

In order to be able to make statements about children's creativity, a suitable test instrument is needed. In line with current research, creativity was operationalized as first step for this project (Holzapfel et al., 2022). The current discourse is clear: creativity is often operationalized as construct that is composed of divergent and convergent thinking and requires both equally (Runco & Jaeger, 2012). Divergent thinking - that is, the flexible, imaginative variation of approaches to solutions - is considered central to this (Cropley, 2006). Guilford (1967) also emphasizes the importance of convergent thinking, which structures selection, evaluation, and decision-making processes. In other words, those who think creatively think innovative and different, but also solution-oriented and goal-oriented (Sternberg & Lubart, 1998).

Creativity research often refers to four sub-areas of creativity: the creative person, the creative process, the creative product and the creative environment (Rhodes, 1961). These sub-areas are all relevant for teaching and learning. The creative person can therefore be a teacher or student, the creative product a learning outcome, the creative environment an appropriately designed classroom and the creative process can be a learning process (Bliersbach & Reiners, 2017).

The project presented here considers all four areas, with the focus being on the creative person, i.e., the creative students.

Purpose Of The Study

Since creativity and the basics of computer science are considered important skills in a modern, fast-paced world, the question arises as to the status quo of these two skills among children of elementary school age. Furthermore, it seems important to examine the interaction between these skills and to develop ways of teaching them. This study therefore investigated the following research questions.

As can be deduced from the theory, creativity is a very complex construct that can be roughly described by specific abilities in both divergent and convergent thinking. In order to make a statement about the creativity of elementary school students, it must be possible to operationalize and measure it. The first research question is therefore:

> RQ 1: How can creativity of elementary school students be measured?

The operationalizability of the construct of creativity should be considered specifically in the context of the basic computer science education of elementary school students. In addition, the question arises as to what prior knowledge in basic programming skills the children have and whether it is possible to develop a successful intervention to promote basic programming skills. This leads to the following question:

> RQ 2: Is the intervention effective for promoting basic programming skills? Are there gender differences or differences between the grades?

In a next step, the question occurs as to the connections between creativity and basic programming skills. The corresponding research question is:

> RQ 3: Is there a relation between creativity (i.e., divergent/convergent thinking) and algorithmic thinking?

Methods

To answer these questions, a half day intervention for the floor-robot BlueBot was developed, and data on basic programming skills (adapted from Zapata et al., 2021), creative thinking (adapted from Landmann et al., 2014 and Torrance, 1966) and demographic information and control variables (joy of learning, use of digital media, interest in technology, age, gender) were collected in a paper-pencil questionnaire in a pre-post design. In addition to this quantitative data, qualitative data (photos, videos and observation sheets) was also collected, but will not be discussed in detail here. In the creative learning intervention, the children were asked to work in tandems to invent a story on a topic of their choice, and to program the robot so that it acts according to the story. To gain initial experience in this process and to express this, the children were given the task of creating a field for the BlueBot on which it would follow a programmed, predetermined path. The tandems were able to design the field individually from wooden puzzle tiles. Each tandem received the following tiles: a start and finish tile, 5 tiles prepared with blackboard varnish, which the children could paint as they wished, and 13 blank tiles on which the BlueBot was allowed to move.

Sample

A total of *N* = 405 pupils from grades two to four from elementary schools in Germany (Ø 8.29 years; 202 girls and 193 boys, 3 non-binary/other genders, 7 missing values) were surveyed. Participation was voluntary and school management, and all parents gave their consent.

Results

With regard to *research question one*, it can be stated that the scaling of creativity was successfully calculated using SPSS. Two parameters, divergent and convergent thinking, were determined using collected data. Divergent thinking was measured via three scales, two figural and one verbal scale, based on Torrance (1966). As with Torrance (1966), a value for Originality, Fluency and Flexibility was determined for each scale. Originality stands for the uniqueness or rarity of the idea, fluency for the number of ideas of a person, and flexibility for the number of different ideas of a person. The values determined for all three scales were converted into an overall value for divergent thinking and then were z-standardized. For convergent thinking, a scale of eight items based on the Compound Remote Associates Test (Landmann et al., 2014) was used and a sum score was calculated. For uniformity, this sum score was also converted into a z-standardization and forms the value for convergent thinking. Based on these two values, four subgroups were formed using a median split. The median split was calculated once for the value of the divergent thinking and again for the value of the convergent thinking. The sample showed a relatively equal split into four groups: low convergent and divergent thinking (n= 104), low convergent and high divergent thinking (n= 94), high convergent and low divergent thinking (n= 98), and high scores in convergent and divergent thinking (n= 109). The group with high values in divergent and convergent thinking can be described as creative based on the literature (Holzapfel et al., 2024).

Regarding to the *second research question*, it can be stated that the children learned significantly overall ($t(399) = -11.24$, $p < .001$, Cohen's $d = -.562$). The prior knowledge was very low ($M = 1.94$, $SD = 2.16$, maximum achievable score 8) and the value of the post-test does not show a very high level of knowledge either ($M = 2.96$, $SD = 2.61$). Even though prior knowledge was very low, there was a clear increase in learning. However, there would have been further potential for improvement.

Table 1: Algorithmic thinking scores separated by grade.

Grade	alg. *(Pretest)*	alg. *(Posttest)*	alg. (*learning gain)*
2	1.38 (1.71)	2.23 (2.44)	.81 (1.73)
3	1.92 (2.29)	2.73 (2.58)	.80 (1.65)
4	2.95 (2.36)	4.63 (2.24)	1.73 (2.04)

alg. = algorithmic thinking

Descriptively, there are gender differences in the basic programming skills pretest scores (f: $M = 1.61$, $SD = 2.06$; m: $M = 2.29$, $SD = 2.23$), as well as in the posttest scores (f: $M = 2.55$, $SD = 2.55$ and m: $M = 3.39$, $SD = 2.61$), which revealed to be significant for both the pretest and the posttest (pretest: $F(1, 393) = 9.67$, $p = .002$, $\eta_p^2 = .024$, and posttest: $F(1, 391) = 10.24$, $p = .001$, $\eta_p^2 = .026$, respectively). With respect to learning gain, both for girls and boys significant results were observed (f: $t(200) = -8.14$, $p < .001$, Cohen's $d = -.574$; m: $t(191) = -7.74$, $p < .001$, Cohen's $d = -.559$), thus, both girls and boys had significant learning gain. A further analysis however did not reveal significant gender differences with respect to learning gain ($F(1, 391) = 1.174$, $p = .279$, $\eta_p^2 = .003$), indicating that girls and boys learned to the same extent.

In addition, some differences between the grades can be reported. There were significant differences between the pretest scores ($F(2, 399) = 16.68$, $p < .001$, $\eta_p^2 = .077$), as well as significant differences between the post-test scores ($F(2, 400) = 29.74$, $p < .001$, $\eta_p^2 = .129$), with higher scores in higher grades (see Table 1). Learning gain also differed significantly between grades ($F(2, 397) = 9.81$, $p < .001$, $\eta_p^2 = .047$), with the highest learning gain in grade four (see Table 1).

A comparison between children with low and high levels of creativity revealed significant differences with respect to pretest and post-test scores for algorithmic thinking (pretest: main effect "convergent thinking": $F(1, 398) = 17.85$, $p < .001$, $\eta_p^2 = .043$; main effect "divergent thinking": $F(1, 398) = 0.093$, $p = .760$, $\eta_p^2 < .001$; interaction effect: $F(1, 398) = 0.002$, $p = .963$, $\eta_p^2 < .001$; post-test: main effect "convergent thinking": $F(1, 399) = 3.53$, $p = .061$, $\eta_p^2 = .009$; main effect "divergent thinking": $F(1, 399) = 0.49$, $p = .485$, $\eta_p^2 = .001$; interaction effect: $F(1, 399) = 0.43$, $p = .514$, $\eta_p^2 = .001$). This would also address the question regarding the connection from *research question three*.

Discussion And Implications

A practicable operationalization of the creativity of elementary school students in the context of an intervention to introduce programming was demonstrated. The elementary school students surveyed had almost no prior knowledge of programming. Against the background of existing but very limited prior knowledge, it seems necessary to teach the basics, especially in view of the rapid technological development. The evaluation presented here shows that the learning unit is suitable for providing initial insights into the basics of computer science. It should be noted that there are differences between boys and girls. The boys achieved significantly higher scores in both the pretest and post-test, but there was no significant difference between boys and girls in terms of learning gains. Although this suggests that the intervention is equally suitable for boys and girls, it also shows that it did not succeed in raising girls' algorithmic thinking skills to the level of boys. In addition, there was a significant difference in algorithmic thinking between the grades. Overall, algorithmic thinking skills increase continuously from grade two to grade four with fourth graders achieving almost twice as high scores as children in grades two and three in terms of both pre- and post-test results and learning gains. It therefore appears that the intervention is most suitable for children in grade four with respect to algorithmic thinking skills. However, other constructs like for example developing interest and self-concept regarding Computer Science were not in the focus of the present study and should therefore be examined in the future.

A concrete implication for practice based on the data collected is that the synergy between creativity and programming skills is not only successful but also extremely useful and both can benefit from each other. This applies especially to convergent thinking. If we succeed in promoting this, it could probably have an impact on the algorithmic thinking. The results of this study already indicate this, but further analyses should be carried out in order to be able to make a more precise statement here.

On this assumption, further research should be conducted to repeat or extend the intervention with other learning robots in order to achieve a possibly even higher effect and also to determine whether the results of this study can be replicated or even improved upon with other robots. It would also be very informative and exciting to look at how the tandems interact with each other on the basis of the data already collected or additional studies. In this context, it would be interesting to see what influence the creativity of both children and their programming skills have on the creation and design of the stories and the coding. Further, it would also be interesting to take a closer look at the differences between the grades or genders. The results of the study presented suggest that second and third graders may have even more difficulties with algorithmic thinking, whereas fourth graders demonstrate much better skills. Therefore, further studies should clarify whether this is only a phenomenon of the present intervention or measurement, or how and when algorithmic thinking skills need to be addressed. Further, gender differences need to be addressed more explicitly.

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Not Produced "For The Wastebasket" – Materials In The Fops Project

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The new primary schools curriculum in Austria (BMBWF, 2023) places greater emphasis on inquiry-based learning in science studies. To support teachers, the FoPs project is developing teaching materials based on four pillars. In addition to inquiry-based learning, these pillars are scientific ways of thinking and working, using concrete matter (German: die Sache) as a starting point, and the scaffolding of language. Based on a common research question, all materials enable internal differentiation in lessons. Therefore, materials based on the same research question are provided for structured inquiry (Level 1) and guided inquiry (Level 2) of inquiry-based learning. A teachers' guide is also provided. The materials were used by teachers in general studies (German: Sachunterricht) in an initial evaluation phase. To ensure the materials are used beyond the project period, a questionnaire was developed and conducted with primary school pre-service teachers on Bachelor Level. The aim was to find out what is necessary for pre-service teachers to integrate these materials into their lessons in the long term and what improvements they would like to see.

Keywords: Primary Science Instruction, Science Practices, Learning Environments,

Introduction

Basic scientific literacy should be introduced in science teaching at primary level (AAAS, 2012). In Austria there is a main subject called Sachunterricht (general studies) which includes social studies and natural sciences. The aim of this subject is to offer learning opportunities to convey concepts, promote scientific ways of thinking and working, and address nature of science. This is where FoPs ("Forschendes Lernen in der Primarstufe" that means inquiry-based learning in primary education) comes in. Three institutions are cooperating in this research and development project to promote inquiry-based learning at primary school (Nosko et al., 2025; Puddu et al., 2024). In doing so, different learning opportunities are developed based on a specific matter to promote scientific ways of thinking and working. "The soup" is one of these learning opportunities, for which teaching materials and a teachers' guide have been created. Soup powder is a quick way to make soup, and it is probably found in almost every household. Most students are familiar with it, and many learning opportunities related to chemistry, physics, social sciences or economics can be developed based on the scientific phenomenon of solubility.

Conception Of The Materials

The materials in the FoPs project are based on four pillars that are anchored in the primary school curriculum (BMBWF, 2023): a) starting with the matter at hand, b) scientific ways of thinking and working, c) the use of inquiry-based learning with varying degrees of openness and d) language support.

The Four Pillars

When Köhnlein (2022, p. 39f) writes about the "matter of general studies" (Sache), he is referring to everything that gives rise to a discussion or investigation. He is not only referring to real objects, but rather to "objects of our thinking and speaking". Matter always exists in a certain factual context. This implies that subject lessons must never focus on just one aspect of the topic.

It is important to also consider the social, environmental, technical or historical aspects of a matter.

Scientific ways of thinking and working can be seen as diverse methods of encountering new knowledge. This gives pupils in science lessons the opportunity to engage intensively with matters and explore them in depth. According to Nerdel (2017), these ways of thinking and working have a dual function: on the one hand, the understanding of important technical aspects should be ensured, and on the other hand, methodological skills should be acquired. When choosing specific scientific ways of thinking and working for the project, we are guided by Steffensky's description (Steffensky, 2018): Asking questions, hypothesising, measuring, planning and conducting investigations, observing, comparing, ordering, classifying, analysing and interpreting data, drawing conclusions, generalising, arguing, using models, and documenting.

To understand scientific ways of thinking and working, it is helpful to adopt an inquiry-based learning approach. Many aspects of research correspond to the aforementioned scientific ways of thinking and working, which are brought together in an inquiry-based learning process, actively experienced by the pupils.

Through inquiry-based learning, it is possible to develop skills that are required under the keyword 21st Century Skills (National Research Council, 2012) in the primary school curriculum. These skills include asking a question, investigating this question creatively and collaboratively using suitable methods, observing, experimenting, collecting data and drawing conclusions in order to answer the question posed at the beginning. All of these skills are part of inquiry-based learning but can also be practiced individually under certain circumstances (NGSS Lead States, 2013). Depending on the question, different scientific ways of thinking and working can be used and promoted.

If inquiry-based learning is implemented in the classroom, this can take place with varying degrees of openness (levels 0 to 3, see table 1) (Blanchard et al., 2010). The FoPs project materials were developed at levels 0, 1 and 2, enabling work to be carried out at different levels based on the same research question.

Table 1: Levels of inquiry (Blanchard et al., 2010, p. 581).

	Source of the Question	Data collection Methods	Interpretation of Results
Level 0: Verification	Given by teacher	Given by teacher	Given by teacher
Level 1: Structured	Given by teacher	Given by teacher	**Open to student**
Level 2: Guided	Given by teacher	**Open to student**	**Open to student**
Level 3: Open	**Open to student**	**Open to student**	**Open to student**

When implementing scientific ways of thinking and working, spoken and/or written language is essential. Children need to be able to put their thoughts, questions and arguments into words to be able to successfully discuss them with others. Many learners find this difficult. Appropriate scaffolding is therefore important to promote the transition to academic language and terminology in subject lessons through language-sensitive subject teaching (Gabler et al., 2020; Leisen, 2013; Lembens & Krebs, 2025; Quehl & Trapp, 2015) and also to enable participation with regard to highly diverse school classes.

The Materials In The Project

“The soup”, “The snow” or “My classroom” are some of the learning opportunities designed as part of the FoPs project. The subject is always a concrete matter that is physically available in the pupils' immediate environment. Dealing with it provides many opportunities to familiarise with and apply scientific ways of thinking and working in the classroom. When creating the learning opportunities, care was taken to ensure that a multi-perspective approach is possible, as required by the curriculum for general studies (BMBWF, 2023, p. 1). This makes it possible to link the areas of competence (social science, natural science, geography, technology, history and economics) in a structured, meaningful and appropriate way when dealing with the content.

Extensive materials for teachers and students are available for each topic. Meaningful symbols have been used in the text for better orientation and easier readability. In order to provide teachers with the best possible support for their lesson planning, the teachers’ guide contains the following elements: a brief description of the respective matter, a detailed presentation of the individual investigation sheets with a description of the scientific thinking and working methods to be practiced, the levels of inquiry-based learning and the required materials for the investigations, a list of possible links to all areas of competence in science teaching, and ideas for the solution of the students’ investigation sheets. The explanation of the content is provided at different levels of difficulty, one for teachers and one for pupils.

The investigation sheets for pupils are differentiated and named as follows: A) Sheet for all researchers (the basic exploration of the matter using all senses); B) Sheet for beginning researchers is based on level 1 of inquiry-based learning (Both research questions and concrete suggestions for carrying out scientific investigations are provided on the sheet and are worked on by pupils.); C) Sheet for advanced researchers is based on level 2 of inquiry-based learning (Research questions are formulated, the planning and execution of the scientific investigations as well as the interpretation of the observations or collected data are the responsibility of the pupils.).

Research Design

In addition to a classic evaluation design which we used to further develop the materials, we wanted to think ahead. We were interested in learning what features concerning learning materials teachers and pre-service teachers expect so they use materials repeatedly even after the project period ended. Therefore, the research questions of the study presented here are: What is necessary for teachers to integrate our materials into their lessons in the long term? What are their wishes for the provided materials? To what extent do the materials meet their requirements?

To answer these questions, a questionnaire consisting of five sequences was conducted (Baur & Blasius, 2019). A four-level Likert-scale was used, ranging from “very important” to “not important at all”. The first part is about the importance of different aspects of the subject “scientific studies” like perceived importance of inquiry-based learning or nature of science. The second part addresses the preparation of lessons. Sample items are “The time required for preparation is minimal.”, “There is easy access to the materials.” or “The additional consumables (glasses, pens, …) for the investigations are easily available.” The third part shifts the focus to the pupils with statements like “The pupils have fun with the materials.”, “Accessibility for all pupils (screen reader, colors, design) is given.” or “Linguistic differentiation is possible with the materials.” The focus of the fourth part is on the teachers’ guide with the following items: “The desired competencies of the pupils are specified.”, “Lesson plans are available.” or “Suggestions for possible solutions are given.” The final section deals with the alignment of the pre-service teachers' ideas with the materials from the FoPs project.

40 pre-service teachers on the Bachelor's degree program in Primary Education (7 male, 33 female, 0 diverse) completed the questionnaire. The participants' progress in their studies varied greatly. 21 were in the 3rd semester, 12 were in the 7th semester. The remaining seven pre-service teachers were in their 5th to 9th semester. 17 of the 40 pre-service teachers are currently teaching part-time in a primary school, two even full-time.

Findings

This section presents the answers of the pre-service teachers, beginning with an evaluation of the importance of different aspects of the subject "general studies" (see figure 1). The most important aspect is the importance of natural sciences in everyday life, followed by inquiry-based learning and that the students conduct experiments. In general, the pre-service teachers consider most of the aspects to be important. Only the aspect of "talking about how natural scientists work", which is one of the aspects of nature of science, is considered less important. In Austria, it seems that this topic is still not given the attention it deserves.

Figure 1. How important are the following aspects of the subject?

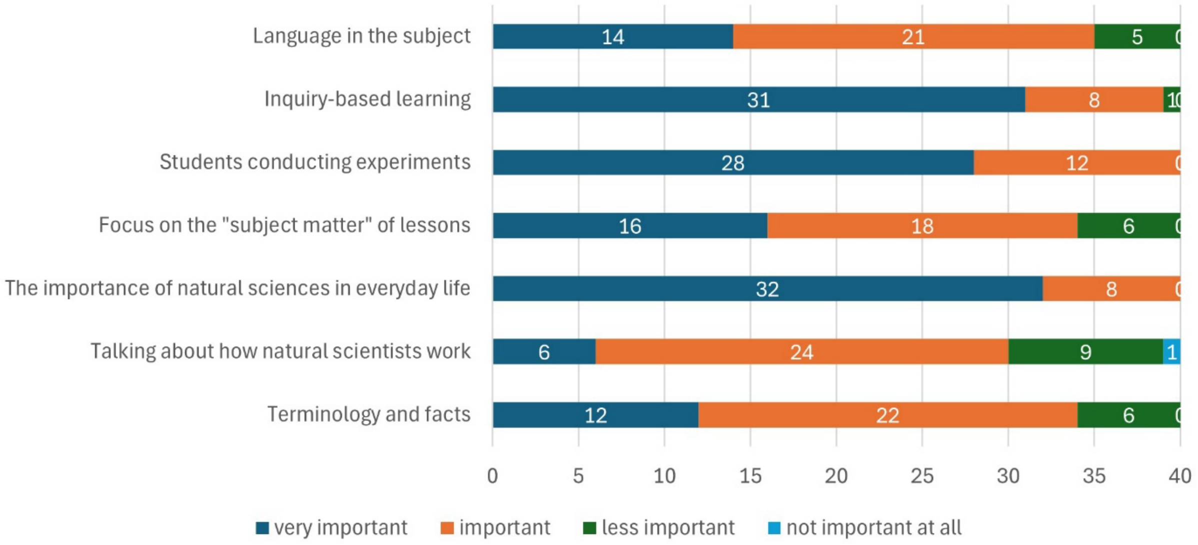


Figure 2 shows relevant criteria concerning pupils with interesting results. While hands-on and minds-on parts are quite important, the item with the highest priority for the pre-service teachers is that the pupils have fun (all 40 pre-service teachers consider it to be either very important or important). Another important criterion is the possibility of internal differentiation in terms of content. 24 pre-service teachers say that it is very important and 15 say that it is important.

The importance of aspects of language was evaluated using two items. Linguistic differentiation is only slightly important (very important: 18), the easy understanding of texts is much more important (very important: 26).

For the pre-service teachers it is important that the pupils can work independently (very important: 23) and that there is a clear and easy-to-understand structure (very important: 26).

Another part of the questionnaire is about the teachers' preparation for the lessons. Figure 3 shows the priorities of the pre-service teachers. The items ranked as "very important" according to the response options are that the materials are easily adoptable and accessible, followed by a digital availability. Interestingly, 26 pre-service teachers stated, that it is "less" or "not important" if additional work like cutting out or crafting is necessary. Only 10 out of the 40 pre-service teachers said that a minimal preparation time is "very important".

Figure 2. How important are the following criteria concerning students?

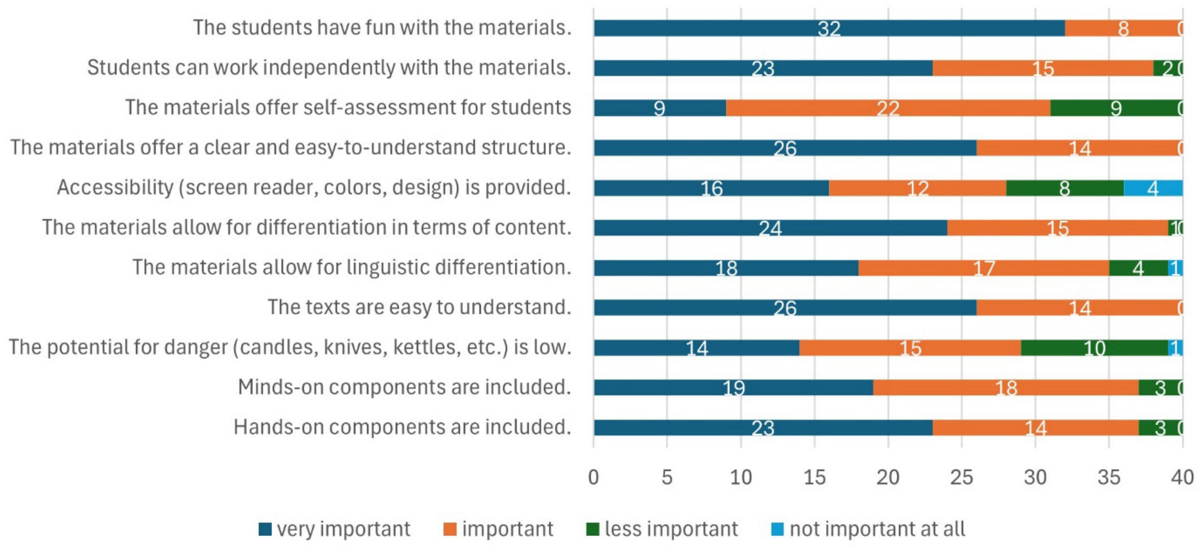


Figure 3. Preparation of lessons

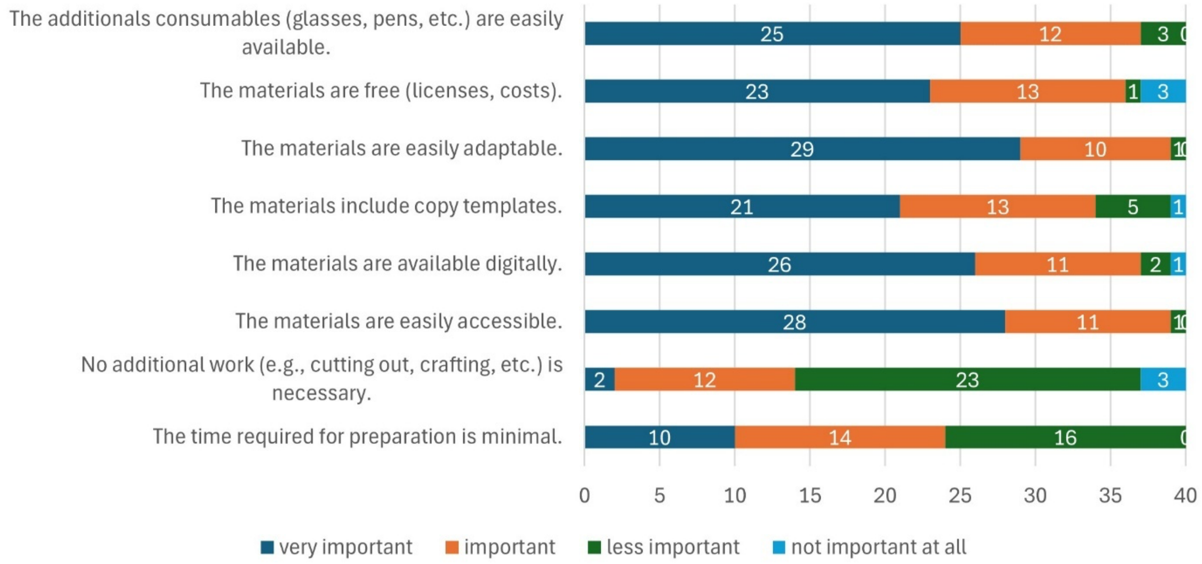


Figure 4 illustrates the fit between the pre-service teachers' expectations and the project materials. It seems that the expectations have been well met. The lowest level of acceptance was shown concerning the preparation.

At the end of the questionnaire, the teachers' students had the option to write a comment. There, comments like "Cool idea, I'd definitely try that out in class!" but also "The presentation seems a bit monotonous/boring." could be found. The comments were varied, but not helpful in terms of further development.

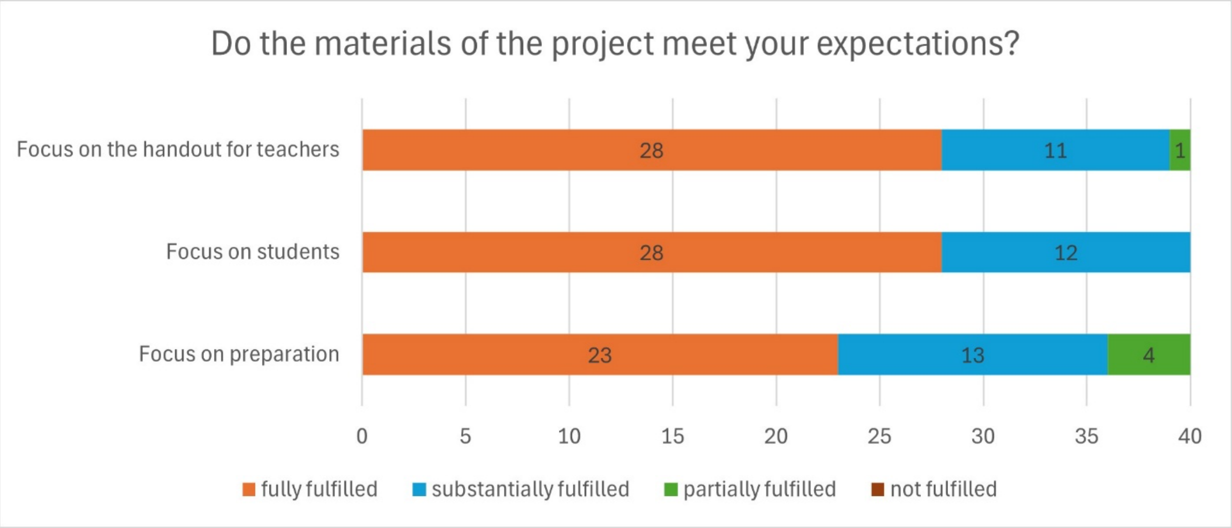
Discussion

In this paper, we presented the findings from a questionnaire completed by pre-service teachers.

The aim of our project was to create materials that are used even after the project is finished. To learn more about the features the materials need to have, a questionnaire was conducted.

The pre-service teachers have very different expectations. It is impossible to meet them all at the same time. Therefore, some compromises must be made between the following three juxtapositions.

Figure 4. **Do the materials of the project meet your expectations?**



Short information vs. exact description: One point that was raised in the open section of the questionnaire was the amount of text in the teachers' guide that had to be read. The desire for shortening and simplification is understandable. However, the problem with this is that something always gets lost when things are shortened. This contradicts the goal of carrying out the teaching as intended.

Easy adaptability vs. intended structure: It is great that pre-service teachers are willing to invest time for adaptation to the respective learning groups. To enable them to meet the needs of their pupils, it would be desirable to provide an easily modifiable format. However, the worksheets are based on findings from the literature and have been evaluated before dissemination. Therefore, revising the worksheets is not always desirable from the authors' perspective.

Student-oriented vs. scientific-oriented: The questionnaire revealed that pre-service teachers tend to prioritise simplification and children's enjoyment. They focus mainly on the children and their experiences when planning lessons and teaching. Content and scientific concepts play a minor role. This approach disadvantages children from educationally disadvantaged backgrounds (Fölling-Albers, 2022). The project materials are intended to support the currently required addition of a science orientation to the curriculum.

However, there are some questions open. It is still unclear what motivates (pre-service) teachers to engage more intensively or in greater detail with the materials. How long do teachers need to decide for or against this? In any case, the successful combination of professional development courses with the distribution of materials can be relied upon (Lipowsky & Rzejak, 2021).

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Exploring Science Through Screens: An Analysis Of Mobile Apps For Preschoolers

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Mobile applications are becoming an increasingly common part of the everyday experience of preschool children, including their encounters with science-related content. However, the pedagogical structure of these digital environments has not yet been adequately examined. This study explores how scientific content is presented in mobile apps designed for early childhood education. A qualitative content analysis was conducted on 14 science-themed apps, which were selected through a systematic search of the Apple App Store and Google Play Store between December 2024 and January 2025. The analysis focused on five dimensions: Scientific content; pedagogical appropriateness; motivation; inclusivity; and science communication. The findings suggest that life science themes (e.g. plants, animals and life cycles) are more prevalent than physical or earth science topics. Applications commonly include visually rich, reward-based interaction patterns that may help to sustain engagement. However, explicit conceptual explanations, scaffolded guidance and opportunities for dialogic or inquiry-based interaction are limited within the apps themselves. Feedback structures generally focus on task completion rather than reasoning processes. Inclusive representations are present in some cases, but not systematically. Overall, the apps appear to provide exposure to scientific phenomena, while features associated with deeper conceptual support are less visible. This study provides a descriptive overview of current design trends and could inform future research and development efforts aimed at enhancing the pedagogical quality of digital science experiences in early childhood.

Keywords: Early Childhood Science; Educational Apps; Mobile Learning; Science Communication; Preschool STEM

Introduction

Young children are inherently curious, driven by an intrinsic desire to explore and make sense of the world around them (Jirout & Klahr, 2012). Research characterizes preschoolers as little scientists who actively seek to understand biological and physical phenomena through observation and explanation (Gopnik, 2012; Zimmerman, 2007). From early childhood, children display sustained interest in how nature works, positioning science as a particularly meaningful domain within early education (French, 2004). Engagement with scientific content can further stimulate this curiosity. Studies indicate that exposure to science topics increases children's motivation to learn and supports the development of scientific vocabulary and discourse (Oppermann et al., 2018; Peterson & French, 2008). With digital technologies becoming an integral part of life today, mobile applications offered on smartphones and tablets are among the primary environments where children can interact with science.

In contemporary childhood, digital technologies—particularly mobile applications on tablets and smartphones—have become prominent environments where children encounter scientific ideas. The National Association for the Education of Young Children emphasizes that technology and interactive media can be valuable learning tools when used intentionally and in developmentally appropriate ways (NAEYC & Fred Rogers Center, 2012). Empirical studies support this position, showing that well-designed digital experiences can positively influence learning outcomes in early childhood (Bullock et al., 2017; Xie et al., 2018). Touchscreen educational apps, for instance, have produced meaningful gains in early literacy and mathematics (Griffith et al., 2020; Outhwaite et al., 2022). Within science education specifically, research demonstrates that preschoolers can learn new factual information through interactive apps as effectively as through direct instruction (Kwok et al., 2016) and that mobile game contexts can support understanding of physical science concepts such as projectile motion (Herodotou, 2018). These findings suggest that thoughtfully designed science apps have the potential to enhance conceptual learning and scientific understanding during early childhood.

Contemporary evidence suggests that pre-school children spend around 2–3 hours a day on screen-based activities (Chang et al., 2018; McNeill et al., 2019), devoting almost an hour of this time to using mobile apps (Rideout & Robb, 2020). This level of exposure highlights the important role that app design plays in shaping early learning environments. When used in supportive contexts, educational technology can meaningfully contribute to early childhood development and learning (Clements et al., 2024). Consequently, the pedagogical quality of mobile applications, particularly those accessed via tablets and smartphones, becomes a central concern in early education research. Despite this extensive engagement, there is limited systematic knowledge about the scientific content that children encounter in mobile apps. In Turkey, there is a notable absence of comprehensive analyses examining the science-related content of children's mobile applications. A recent study evaluating STEM-oriented mobile apps (Konca et al., 2024) found that most of the apps were in English and that evaluations focused primarily on general app features rather than the scientific content, conceptual accuracy or science communication practices. Consequently, our understanding of how science is represented, structured and communicated in digital environments frequently accessed by young children is inadequate. A comprehensive examination of the scientific content embedded in preschool mobile apps is therefore necessary. Such analyses could shed light on the current state of digital science learning environments and provide a foundation of evidence to guide parents, educators, and developers in creating developmentally meaningful and pedagogically sound early science experiences.

Method

This study employed qualitative content analysis to examine mobile applications designed for preschool children (aged 3–6) that contain science-related content. A systematic search of the Apple App Store (iOS) and Google Play Store (Android) was conducted between December 2024 and January 2025. Search terms included science, ages 3–6, preschool, early childhood, and popular. Additional scans were conducted within the Education and Kids categories, and the most downloaded and highest-rated children's applications were examined. The search and selection procedures were documented to ensure transparency and reproducibility of the sampling process.

Applications were included if they explicitly contained scientific content (e.g. topics related to life sciences, physics, or earth sciences) and targeted an early childhood audience. Applications that focused solely on general early learning without science-related components were excluded. Based on these criteria, 20 applications met the initial inclusion threshold. The sample included both free and paid applications that were widely used by children in Turkey, ensuring that the analysed content resembled real-life usage contexts. Although 20 applications met the initial search criteria, a secondary eligibility screening was conducted during the coding phase to ensure that apps contained accessible science content relevant to preschool learners. Applications in which science-related sections were locked behind paywalls, lacked substantive science content despite categorical labeling, or targeted broader age ranges without developmentally appropriate science activities were excluded from full analysis. Following this refinement, 14 applications constituted the final analytical sample. This step enhanced the ecological validity of the content analysis by ensuring that findings reflected children's actual exposure to science-related experiences within apps. Table 1 presents the final set of applications included in the analysis, along with their primary science domain classifications.

Table 1. Primary dcience domains represented in the analysed preschool science apps.

App Name	Primary Science Domain
MarcoPolo Weather	Earth Science (weather, seasons, atmosphere)
TRT Çocuk Anaokulum	Mixed (plants, animals, environment)
Sevimli Dostlar	Life Science (animals, plant growth, health themes)
What’s in the Ocean	Life Science (marine life, ecosystems, food chains)
Caillou	Life Science (living–nonliving, plant/animal care)
TRT Çocuk Oyun Dünyası	Mixed (plant growth activities)
Farm Games for Kids	Life Science (farming, animals, food sources)
Animal Farm for Kids	Life Science (farm animals, habitats)
Minikler için Eğitici Oyunlar	Life Science (animals, plants)
Playo	Mixed (nature, weather, environmental elements)
Maşa ile Koca Ayı	Life Science (farming, animals, plant growth)
Eşle ve Öğren	Life Science (animals, plants)
TRT Kare	Mixed (day–night, hot–cold)
Science Games	Mixed (life cycles, states of matter, space themes)

The coding framework followed a conventional qualitative content analysis approach as described by Hsieh and Shannon (2005). Rather than applying a predefined coding scheme, codes emerged through repeated interaction with the apps, enabling patterns specific to preschool science applications to be identified. At the same time, existing academic work in early childhood education and digital learning provided theoretical guidance without constraining interpretation (e.g. Bruner & Kúcelová, 2024; Callaghan & Reich, 2018; Clements et al., 2024). This approach ensured that the analysis remained data-driven while aligned with existing research on educational media and early science learning. The coding framework consisted of five categories: Scientific Content, Pedagogical Suitability, Motivation, Inclusivity, and Science Communication. Subcodes addressed conceptual accuracy, misconceptions, scaffolding, reward structures, diverse representation, accessibility, and communication models.

The analysis was conducted by two coders. The primary coder engaged with each application for approximately 15–20 minutes, systematically documenting interface structure, task flow, and science-related content. Code definitions were subsequently refined. The second coder was trained on the framework, and both coders jointly coded five pilot applications to calibrate code application. The second coder then independently coded 30% of the sample. Disagreements were discussed and resolved, resulting in a final coding scheme with explicit definitions. Inter-coder reliability was high (Cohen’s κ = .94). Analytical notes were used to identify cross-case patterns.

This study involved analysing publicly accessible digital applications and did not include human participants, personal data or identifiable user information. Accordingly, formal ethical approval and informed consent procedures were not required in accordance with institutional research ethics guidelines.

Results

The results are organized according to the five analytical dimensions guiding the coding framework: Scientific Content, Pedagogical Appropriateness, Motivation, Inclusivity, and Science Communication.

Scientific Content

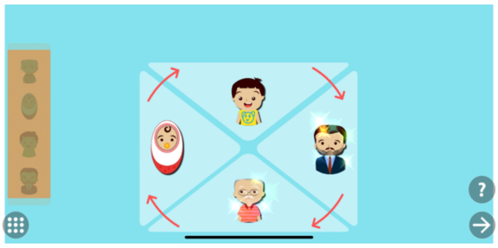
The analysed applications were dominated by life sciences content. Most of the applications focused on biological and nature-related themes, such as plants, animals and health. Gardening simulations were popular, involving children planting seeds and watering the soil, before observing fruits or vegetables appear almost instantly, sometimes after just one interaction. Despite these accelerated representations, some applications presented scientifically accurate concepts. For instance, the app depicted in Figure 1 accurately positioned roots and shoots to depict plant growth, correctly representing both underground and above-ground structures. Animal themes were also prevalent, ranging from farm animals to insects. Many applications included repetitive sequences, such as life cycles or the stages of vegetable cultivation. Figure 2 illustrates the human life cycle, and the same application presents the life cycles of butterflies and frogs, visually highlighting the differences between species. While these topics were consistent with children's familiarity with nature and living organisms, the limited diversity of disciplines was evident. Content related to physics and earth sciences was scarce, suggesting that the applications primarily focused on life sciences.

Figure 1.

Accurately positioned vegetables

Figure 2.

Human life cycle



Although the apps generally aimed to present accurate information, various forms of scientific inaccuracy were observed. A common pattern was the oversimplification of processes. In particular, instantaneous depictions of plant growth misrepresented the temporal dimension of biological development. Anthropomorphic representations were also frequent. For example, in one app a *queen bee* character appeared dressed in human clothing and behaved as a royal figure. Figure 3 shows a crowned cartoon bee character illustrating this type of representation.

Figure 3.

Anthropomorphic Bee Character

Figure 4.

Sunlight and Microorganism

Furthermore, some scientifically grounded phenomena were presented in a way that could lead to misunderstandings. In one app, for example, children were asked to hang out the washing and position it so that it would receive sunlight. The drying process was shown gradually. However, the underlying mechanism of heat transfer was not explicitly represented. In the same section, when the children zoomed in on the clothes, visual depictions of microorganisms appeared and then disappeared when the sunlight icons were shown (see Figure 4). Scientific literature indicates that sunlight can reduce the survival of pathogens and the risk of infection (Hobday & Dancer, 2013). In this section, relevant concepts were linked to observable outcomes, but cause-and-effect relationships were not explicitly defined. Consequently, the representations operated through surface-level causal framing rather than mechanistic explanation. Using sunlight icons as visual representations may evoke the idea of sunlight as tangible particles, which could lead to conceptual misunderstandings.

Pedagogical Appropriateness

Each app's design was examined in terms of its alignment with developmentally appropriate practices for preschoolers. The majority of apps maintained simple interfaces and instructions, minimizing text and relying primarily on visual elements, icons, and audio cues. These design features align with the early literacy levels typical of preschool children. However, the depth of learning observed across apps was generally limited. Built-in progression mechanisms that extend learning beyond basic task completion were scarce. Gradual increases in difficulty and the introduction of more complex concepts in later stages were rarely observed.

In most apps, the cognitive demand of tasks remained relatively constant, while different life science concepts were introduced across successive sections. The sequence of concepts appeared to move from topics likely to be more familiar to children (e.g., plant cultivation) toward less familiar domains (such as fishing, beekeeping, and sheep shearing). Later stages included more specific contextual concepts. For instance, one app presented a task requiring drainage of water accumulated around a cherry tree following rainfall. In this section, children were required to complete the action correctly before progressing. However, the concept of *drainage* was not explicitly named in text or speech; the process was presented solely as a task-based interaction. In such cases, concepts were embedded within activities but were not accompanied by explicit conceptual labelling or integrated explanation.

Another dimension of pedagogical design concerns how apps guide children during learning. Educational applications for preschoolers are typically expected to provide scaffolding through hints, modelling, or feedback that supports learning from mistakes. Most apps in the sample adopted a trial-and-error approach. Children could interact freely, correct actions were reinforced through positive feedback, whereas incorrect actions were typically addressed through brief auditory cues or simple redirection. Instances of explanatory feedback were not observed. This pattern indicates that opportunities for explicit conceptual clarification were limited within the apps' feedback structures.

Motivation

Consistent motivational design features were observed in all applications. One such feature was the widespread use of instant feedback systems. Almost all applications reinforced children's actions with lively sounds, animations and celebratory visual elements. Upon completing a task, stars, music or enthusiastic character reactions were often displayed on the screen to provide immediate reinforcement (see Figure 5). These feedback events occurred rapidly and at frequent intervals throughout interactions. Reward structures extended beyond symbolic indicators. Many apps incorporated progression-based systems that unlocked new content or virtual collectibles upon completing a level. Gamification elements such as points, badges and level advancement made progress visible within the app environment. Stars were particularly common as a performance marker, serving as a visual representation of achievement (see Figure 6).

The narrative framework and character design further supported interaction. Various activity formats and animated characters were widely used. Some apps featured well-known characters that children would recognise from YouTube, cartoons or books. This placed learning activities within familiar narrative contexts. In such cases, these characters served as guides or participants in science-related activities. Several applications featured adaptive pacing, where the transition speed or task flow changed based on the child's interaction speed. Although not common, these design models were present in multiple applications. Elements supporting autonomy were also present, allowing children to select activity centres within the application and choose between different characters or task paths.

Figure 5.

Instant celebratory feedback

Figure 6.

Star-based reward

Inclusivity

The inclusivity analysis addressed both on-screen representation and accessibility for diverse users. In terms of representation, the diversity of characters and contexts was limited across most of the apps. Many featured animal protagonists or generic cartoon children without clearly identifiable racial or cultural backgrounds. When human characters were present, some degree of gender diversity was evident. However, only one app in the sample displayed more explicit inclusive representation. In this underwater exploration-themed app, the diver characters were portrayed as a girl and a boy. One character was depicted as a light-skinned boy and the other as a dark-skinned girl. The characters worked together and had equal roles in scientific exploration. In this example, both gender and ethnic diversity were visually represented. However, none of the apps addressed cultural dimensions of science, such as scientists from different parts of the world or references to traditional knowledge systems. Notably, there were no characters with visible disabilities. There were no depictions of mobility aids or assistive devices, nor any scenarios reflecting differently abled individuals. Overall, these preschool science apps appeared to depict a relatively homogeneous landscape, largely reflecting able-bodied and Western-oriented contexts.

Science Communication

The apps were examined to see how scientific information was presented, and whether children were encouraged to engage in scientific reasoning or dialogue. Overall, the apps were found to follow a one-way 'show-and-tell' approach, which is consistent with a deficit model of science communication. Information or outcomes were usually presented for the child to absorb, rather than encouraging active thinking or inquiry. For instance, in one app, when a child waters a virtual plant, the narration says, 'Let's water it so it can grow', accompanied by a watering icon. However, the child is not asked to consider how or why this process occurs. Although the communication format was embedded within interactive gameplay, it was largely scripted and instructional in nature. No dialogic communication model, in which children are asked open-ended questions or encouraged to express their ideas, was observed. Interactive elements such as reasoning-based multiple-choice prompts (e.g. 'Why do you think this happens?') were not present. A participatory communication model, in which children record observations, make predictions or freely explore and draw conclusions, only appeared in limited forms. Some apps included sandbox-style exploration areas where children could mix materials and observe the results. However, even in these cases, the apps did not provide scientific explanations for the phenomena observed.

Scientific content was predominantly conveyed through visual and animated representations. Processes such as seed germination were demonstrated through animation. However, these representations did not incorporate explanatory dialogue or conceptual justification. In summary, science communication in preschool science apps was characterised primarily by one-directional information delivery. While the apps focused on demonstrating phenomena, there were limited opportunities for interaction requiring questioning, explanation or verbalisation of ideas.

Discussion

The analysis of 14 preschool-oriented science applications indicates the presence of highly engaging yet pedagogically under-supported digital learning environments. The findings suggest that while these applications increase children's access to scientific content, they remain limited in meeting core principles of early childhood science learning. One of the major strengths of the apps is accessibility. Consistent with research demonstrating that children can acquire scientific knowledge through interactive media (Kwok et al., 2016), the apps provide exposure to scientific concepts that children might not encounter before formal schooling. The predominance of life science themes reflects developers' tendency to capitalize on young children's natural interest in animals and plants. However, the limited representation of physical and earth sciences points to a narrow interdisciplinary scope. Early childhood science education aims for a balanced distribution of domains, including physical science concepts such as forces and materials (French, 2004). The current distribution may reinforce, for preschool children who spend extensive time with apps, the perception that science is primarily equivalent to nature.

The anthropomorphic representations and depictions of instantaneous biological processes observed in the apps raise pedagogical concerns regarding potential misconceptions. Anthropomorphic narratives can enhance engagement and may even foster positive attitudes toward animals (Reider & LoBue, 2024). However, Bonus and Mares (2019) demonstrated that preschool children's ability to evaluate the reality status of information presented in educational videos is associated with learning and transfer, suggesting that distinguishing real from fictional elements may not be straightforward for young learners. In most of the apps analysed, this distinction was not explicitly clarified. This finding aligns with early childhood teachers' concerns that anthropomorphism may contribute to cognitive confusion (Kallery & Psillos, 2004). Given that misconceptions acquired in early childhood can persist over time, clearer separation between anthropomorphic elements and scientific explanations becomes essential.

Motivational design features constitute one of the strongest aspects of these applications. Frequent rewards, gamified progression, and celebratory feedback mechanisms help sustain children's engagement. Positive emotional experiences with science in early childhood are known to support later motivation for science learning (Jirout & Klahr, 2012). Nevertheless, the intensive use of extrinsic rewards raises questions regarding depth of learning. In edutainment designs where game elements are appended as external rewards to learning elements (e.g., *the chocolate-covered broccoli* approach), attention and flow may shift from educational goals to game goals. Indeed, lower levels of learning-task engagement have been reported under extrinsic design conditions. In contrast, the intrinsic integration approach, in which learning content and game mechanics are structurally unified, enables motivation and cognitive engagement to align toward the same objectives, resulting in a more balanced learning experience (Habgood & Ainsworth, 2011).

Another critical limitation concerns feedback structures. While apps celebrate correct responses, they rarely explain why incorrect responses are wrong. Encouraging children to explain phenomena is known to strengthen conceptual understanding (Zimmerman, 2007). Transforming errors into explanatory learning opportunities could more effectively connect motivation with learning processes. Regarding inclusivity, the findings parallel broader trends in children's digital media. Although gender representation appeared relatively balanced, ethnic diversity and representations of disability were largely absent, aligning with research indicating limited diversity in preschool applications (Bruner & Kucirkova, 2024). The analysis also showed that characters were predominantly animals or humans. This may be coded as a potentially inclusive feature, as animal characters can serve as culturally neutral figures that transcend specific social identities (Williams, 2014).

The most prominent pedagogical gap emerged in the domain of science communication. The apps predominantly adopted one-directional information delivery. Phenomena were visually presented, yet opportunities for questioning, explanation, and dialogic interaction were limited. Early science education literature emphasizes that guided inquiry and conversational exchanges are critical for conceptual development (Peterson & French, 2008). The absence of such dialogic processes may result in these apps functioning more as visual information sources than as interactive learning tools.

Limitations and Implications

This study is based on a qualitative content analysis examining the pedagogical structure of science-focused mobile applications designed for the preschool age group, and therefore carries several limitations. First, the sample was limited to 14 applications selected through a systematic search conducted between December 2024 and January 2025 on the Apple App Store and Google Play Store. Given the dynamic nature of app ecosystems, rankings, visibility, and availability of applications may change over time. Accordingly, the findings represent a snapshot of popular content within a specific time frame. Second, the study did not include direct measurement of children's learning outcomes. Evaluations were grounded in expert interpretation of app content features, pedagogical design elements, and the early childhood science education literature. Therefore, the results offer inferences about the potential learning affordances of the applications but do not experimentally verify actual learning gains. Third, the analysis focused on the design characteristics of the applications, without examining how children and caregivers experience these apps in naturalistic use contexts. App engagement is shaped by multiple factors, including adult guidance, duration of use, contextual support, and individual child characteristics. As such, discrepancies may exist between the pedagogical potential identified in the design and the learning experiences that occur in real-life usage.

Despite these limitations, the study provides important implications regarding current pedagogical tendencies in preschool science applications. The findings indicate that while digital designs are strong in motivational engagement, they remain underdeveloped in conceptual structuring, dialogic learning opportunities, and inclusive representation. This suggests a need for digital learning experiences to align more closely with established principles of effective early childhood science education.

Finally, collaborations among researchers, app developers, and educators may enable research findings to more directly inform design processes. Such interdisciplinary approaches are critical for enhancing the pedagogical quality of digital science environments developed for early childhood learners.

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Creative Sparks And Constructive Tensions: How Resistance Shapes Young Children's Collaborative Engineering Design

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This study examines how young children demonstrate creativity during collaborative engineering design tasks in early childhood education. Using a basic qualitative approach, researchers observed 17 children (ages 4-7.5 years) engaged in engineering projects at a Montessori summer program. Analysis of conversations during a shelter design task revealed both conventional aspects of creativity (novelty, risk-taking, variety) and an unexpected element: resistance. Rather than impeding progress, instances of resistance—where children challenged each other's ideas—served as catalysts for creative development and solution refinement. Children's resistance fostered deeper engagement with design constraints and facilitated collaborative problem-solving. For example, when children resisted certain design choices, it led to more sophisticated considerations of material properties and physical concepts like light and shadow. These findings suggest that constructive resistance should be recognized as an integral component of creative development in early childhood engineering education, with implications for both research and practice in STEM education

Keywords: Early childhood education, engineering education, critical thinking

Introduction

Engineering education in early childhood has been increasingly recognized as a valuable component of young children's development, yet it remains relatively underexplored in both research and practice (Cunningham & Kelly, 2017). While much attention has been given to literacy and numeracy, the integration of engineering concepts in early education provides unique opportunities for fostering creativity and problem-solving skills among young learners. Early childhood engineering activities, such as building structures, designing simple machines, or experimenting with materials, allow children to explore the world around them in innovative ways, thus laying a foundation for later STEM learning (Moore et al., 2019). Despite this potential, the creative processes children engage in during these activities are often disregarded as valuable (Bolden et al., 2020). In this study resistance appears as an unanticipated analytic finding, emerging as a productive form of participation through which children challenged ideas, negotiated design decisions, and advanced creative engineering thinking.

Framework And Relevant Literature

Creativity is foundational to human development, extensively studied and valued in educational contexts (Rhodes, 1961). Contemporary research underscores it's vital role in fostering critical thinking, problem-solving, and innovation—abilities essential for navigating future complexities (Beghetto & Kaufman, 2017). Defined by divergent thinking, originality, flexibility, and the ability to generate novel solutions, creativity engages multiple brain networks and can be cultivated through intentional educational interventions (Runco, 2014). Notably, resistance, characterized as constructive challenges to ideas, enhances creativity by fostering reflection, idea refinement, and collaborative problem-solving. Pedagogical strategies promoting autonomy, exploration, risk-taking, and constructive resistance effectively nurture creativity across disciplines and educational levels (Beghetto & Kaufman, 2017).

In early childhood education, creativity holds significance as it aligns with young children's inherent tendencies toward imaginative play and exploration. These formative years of peak neural plasticity, provide an optimal period to cultivate creativity (Mohammed, 2018). Imaginative play and exploration underpin cognitive flexibility, problem-solving skills, and emotional regulation (Stoltz et al., 2015). Resistance, through questioning and rethinking, aligns with young learners' propensity to experiment with ideas, challenge peers, and refine their thinking. Play-based learning environments significantly shape creative development, with STEM education offering unique opportunities to integrate creativity. Activities in engineering design, scientific inquiry, and mathematical problem-solving not only require creative thinking but also foster deeper conceptual understanding, engagement, spatial reasoning, and knowledge retention (Stoltz et al., 2015).

Engineering tasks encourage young children to practice divergent thinking, while building critical and emotional skills necessary for future challenges (Moore et al., 2019). These activities support children's curiosity, adaptability, and resilience by prompting (Mohammed, 2018). Resistance plays a central role as children debate ideas, challenge designs, and refine solutions. For instance, questioning material choices or debating structural elements leads to deeper engagement and innovation. Understanding creativity in early childhood STEM education, including the role of resistance, equips educators to design inclusive, engaging experiences that foster creativity and prepare learners for lifelong innovation (Mohammed, 2018).

Creativity In Early Childhood STEM And Engineering Contexts

Creativity in early childhood is central to engagement in STEM and engineering education. Across the literature, creativity is consistently defined as the capacity to generate ideas that are both original and appropriate to the task at hand (Dow, 2022; Joubert, 2022; Peterson & French, 2021; Sternberg & Lubart, 1999). In STEM contexts, creativity manifests through problem-solving, experimentation, and iterative design processes that encourage young children to explore, question, and make sense of the world around them (Lippard et al., 2017; French, 2018).

Many argue that engineering design is a fertile context for fostering creative thinking in young learners. Studies have shown that when children are engaged in design challenges, they naturally exhibit engineering habits of mind like persistence, systems thinking, and creativity (Peterson, 2019; Lippard et al., 2017). This kind of thinking is nurtured through open-ended materials, child-directed inquiry, and opportunities for iteration (Murcia et al., 2022; Simoncini & Lasen, 2018). Creative markers in children's engineering and design work include novel uses of materials, original approaches to solving problems, and verbal or visual expressions that reflect children's reasoning and imagination (Tippett & Gonzalez, 2022; Kuhn et al., n.d.).

Resistance In Young Children's Engineering

Resistance in young children's collaborative group work and engineering activities can be both a site of tension and a source of generative potential. Resistance is not simply oppositional behaviour, but a legitimate form of agency wherein children assert their autonomy, question authority, and reshape their roles in learning environments (Rainio, 2008). Often emerging in social contexts where children encounter externally imposed structures or expectations, resistance shapes how children respond to such events as a teacher's vision for classroom norms or a group's idea of how a project should unfold. Rather than viewing resistance as defiance to be managed or eliminated, Rainio (2008) suggests that it can be a creative, transformative force. In the playworld studied, for example, a child's initial resistance evolved into meaningful participation once the activity allowed space for narrative flexibility and individual investment (Rainio, 2008). Similarly, Litvinaitė (2022) situates resistance within the broader context of cultural negotiation, arguing that resistance can be a productive force that disrupts cultural reproduction and fosters hybrid ways of working and knowing. These insights align with sociocultural views that see agency as emergent from interaction, with resistance offering children opportunities to reconfigure the social and intellectual terms of engagement (Stetsenko & Ho, 2018; Vygotsky, 1978).

In the context of collaboration among young children, especially in early childhood engineering education, resistance may manifest as silence, withdrawal, refusal to follow peers' ideas, or challenging the assumptions embedded in others' proposals (Perumal, 2008; Rainio, 2008). The literature highlights how this behaviour is not necessarily unproductive. Instead, it signals that children are negotiating the norms of participation, authority, and identity within a group. Perumal (2008) emphasized that resistance in collaborative learning contexts often emerges as a response to the shift from passive reception to active engagement, particularly when students are asked to share cognitive or social authority. For young children in engineering tasks, this could look like questioning the utility of a peer's design, insisting on using an unconventional material, or rejecting a plan that doesn't align with their sense of how something should work. While these moments may appear disruptive, they can also prompt critical reflection, negotiation, and innovation within the group. Here, resistance is not a barrier to collaboration, it is a mode through which collaboration can be deepened and made more authentic.

Within early childhood engineering, resistance has particular affordances to advance thinking and design processes. Engineering design is inherently iterative, requiring testing, failure, and re-design (Cunningham & Kelly, 2017). When children resist a suggested solution or choose not to go along with a group consensus, they are engaging in critical evaluation and proposing alternative pathways. Litvinaitė (2022) describes how resistance can lead to greater creativity and the reconfiguration of roles and norms, allowing children to move beyond reproduction of adult-expected designs and toward genuine invention. Rainio (2008) and Perumal (2008) both argue that when children are given space to resist, new forms of agency and understanding emerge. In engineering tasks, this might include a child refusing to use an adult-suggested material because it does not meet the demands of their imagined function, or a child insisting that a tower's stability matters more than height. These actions reveal a depth of engagement with engineering concepts and an investment in the process that extends beyond compliance. Resistance serves as a catalyst for learning, identity development, and the cultivation of collaborative engineering mindsets.

Research Aim And Questions

The following question guided the study:

- How do young children demonstrate creativity when engaged in collaborative engineering design tasks?

Methodology And Research Methods

This study was conducted using a basic qualitative research approach, which allowed for close examination of how young children demonstrated creativity while engaging in collaborative engineering design tasks (Merriam, 2009). This methodology was well-suited to our focus on how children expressed themselves and made meaning through their talk, actions, and shared design experiences. Our goal was to better understand the character of children's creative participation during a summer engineering program. To do so, we analysed transcripts of audio recordings, design products, and interviews with participating children to explore their experiences with and expressions of creativity in engineering contexts (Merriam, 2009).

Context And Participants

The study took place over a five-day period during a summer enrichment program hosted by a public Montessori charter school located in a small community in the Mountain West region. This school, guided by Montessori principles such as hands-on learning, mixed-age classrooms, and learner-directed inquiry, offers year-round learning opportunities (Lillard, 2012, 2017). The summer programming retained these values, offering a flexible and supportive setting for continued exploration and play.

Twenty-four children were enrolled in the week-long program, although attendance varied by day. Participants ranged from nearly four years old to seven and a half years old, with the group comprising eight boys and sixteen girls. For engineering activities, students were grouped into teams of three or four by Montessori staff, who used their familiarity with the students' social skills and dynamics to create mixed-age, mixed-gender groupings.

Engineering Programming

The engineering curriculum used in the study was developed and facilitated by the research team rather than the classroom teachers, who remained in observational roles when present. A member of the research team with a strong background in early childhood and elementary teaching led the activities to ensure both developmental suitability and sound pedagogy. Each day began with a full-group session to introduce the engineering challenge, followed by group-based building and problem-solving. The engineering sessions ran for roughly three hours daily over the five-day period, giving children time to iterate on their designs, build social and collaborative skills, and interact with STEM ideas in tangible ways. The week's activities were adapted from the *Engineering is Elementary* (EiE) Kindergarten curriculum from the Museum of Science, Boston (Museum of Science, Boston, n.d.). The EiE curriculum supports young learners in exploring engineering through structured but age-appropriate tasks that emphasize the design cycle (Ask, Imagine, Plan, Create, Improve), real-world connections, and teamwork (Museum of Science, Boston, n.d.). These elements aligned naturally with Montessori educational goals, which value hands-on work, guided autonomy, and collaborative exploration (Cunningham & Lachapelle, 2014; Lillard, 2016). This alignment enabled smooth integration of engineering into an already inquiry-rich learning environment.

Two EiE units were selected and modified to shape the program: *Here's the Scoop: Designing Trash Collectors* (2018) and *Raise the Roof: Designing Shelters* (2018). The former served as an introduction to testing materials and iterative building in a fun, low-stakes activity. Later in the week, students tackled the shelter-building challenge, which was especially relevant due to a concurrent heat wave. This context helped students see how engineering could solve real-life problems and invited engagement with key scientific and design concepts like heat management, material properties, and structural integrity. The engineering curriculum was thoughtfully designed to root children's creativity in personally meaningful and relevant challenges.

Data Collection

Throughout the week, we audio-recorded all engineering sessions, including morning introductions, small-group work, and end-of-day reflections. Altogether, these recordings totaled over 18 hours. For this study, we concentrated our analysis on approximately six hours of audio captured during the small-group sessions of the *Raise the Roof* activity. This portion of the week's work was selected because it featured rich collaborative interactions, prolonged problem-solving efforts, and dynamic engagement with engineering practices. It provided a particularly strong window into children's creative and social participation.

Data Analysis

We focused our analysis on eight transcripts capturing children's dialogue and collaboration during the *Raise the Roof* engineering task, which asked them to design a sun shelter for a stuffed dog. All audio was transcribed verbatim to preserve the details of the children's language (Saldaña, 2016). We began with a deductive coding framework drawn from the OECD creativity rubric (OECD, n.d.) and the creativity domain of the engineering habits of mind framework (Lippard et al., 2019), both of which view creativity as a process. These initial codes are shown in Table 1.

To begin coding, each researcher individually analysed Transcript #1 using these predetermined codes while also engaging in open coding to allow for emergent insights (Strauss & Corbin, 1998). When we compared our initial codes, inconsistencies emerged, prompting a collaborative process of code refinement. Through discussion, we clarified and revised code definitions, resolved overlapping categories, and added new inductive codes (e.g., such as *resistance* and *uncertainty*) that captured additional nuances in the children's collaborative problem-solving (Charmaz, 2014; Patton, 2002; Strauss & Corbin, 1998).

We then recoded the first transcript using this revised codebook and assessed the alignment of our coding through axial coding techniques (Saldaña, 2016; Strauss & Corbin, 1998). This second round produced much greater consistency among team members. When discrepancies remained, we discussed them until consensus was reached. Using this finalized coding scheme, we independently analysed the remaining seven transcripts. Afterward, we met again to compare our coding results and resolve any further disagreements (Miles et al., 2014; Saldaña, 2016).

Following this final round of coding, we reviewed all coded excerpts and annotated them with interpretations about how they contributed to the unfolding creativity of the design process. This interpretive step helped us identify the ways specific moments and decisions advanced the children's learning and innovation (Braun & Clarke, 2006). We then grouped data by code and examined how themes intersected across categories. Through ongoing collaborative discussion, we refined these cross-code patterns to generate consistent, well-supported themes in our final analysis (MacQueen et al., 1998; Saldaña, 2016).

Results

Across our analysis of the children's dialogue during the engineering task, as they designed and constructed a shelter to keep a dog cool in the sun, we observed the presence of creativity aligned with expected markers. Children generated a variety of novel ideas (coded as *variety* and *novel*), often building on or combining others' contributions in flexible and exploratory ways. They demonstrated risk-taking behaviours, particularly when sharing uncertain or unconventional suggestions (coded as *risk*), and frequently introduced radically new ideas that shifted their group's design trajectory entirely (coded as *radical*). In many instances, children's ideas were grounded in scientific disciplinary knowledge (coded as *connected*), such as reasoning about heat absorption, material properties, or the relationship between structure and function. These connections not only enriched their design justifications but also highlighted how disciplinary thinking supported creativity during engineering. Table 1 (next page) gives examples of each of these markers of creativity, how they surfaced in the data, and how they shaped the engineering design.

In addition to the more expected markers of creativity, a new and unexpected theme emerged during our coding and analysis process – *resistance*. While not initially framed as a tenet of creativity in the literature, resistance surfaced as a meaningful form of participation and marker of young children's creativity when engaged in engineering. At times, children pushed back on each other's suggestions, on design directions, or on the pace of decision-making. Rather than halting progress, this resistance often served to sharpen the group's thinking, slow the rush to consensus, and open space for further elaboration or clarification. In this way, resistance appeared not as a barrier, but as a generative force in the collaborative creative process, shaping how and when new ideas were taken up and how designs evolved.

Table 1. Markers of creativity, examples from the data, and descriptions of how the engineering design was shaped.

Marker of Creativity	Children's Quote from the Data	How the Process was Shaped
Variety	We could put it in the middle and one of us could wrap the tape around to make it stay (Child 14)	Adding on to an existing idea and design choice, pushing the process forward
Novelty	How about we make a circle, a door… (Child 2)	Proposes a new idea to the group, shifting the design ideas and process
Connected	That's, that's, is that skin? (Child 5)	Links knowledge about skin to properties of materials to enable materials choices
Risk	And we, and we might use that (Child 8)	Proses a new material, previously untested and undiscussed, pausing the group to weigh options
Radical	Why the middle? How would it get in the middle? We could just do it on the side and make it cute (Child 1)	Questions the design idea and suggests a change, changing the direction of the original design

We interpreted moments of resistance as instances of critical collaboration, or points in the design process when the children actively contested ideas. These expressions, which were sometimes subtle and occurred less often than other, more prominent themes, reflected important dimensions of creative agency. Rather than simply obstructing progress, children's resistance shaped the course of group decision-making and design development. Children voiced disagreement through short statements (e.g., "No," or "I don't think that will work") to pause the activity, to prompt reconsideration, or questioned material selections, placements, or strategies based. In some cases, doubt was articulated through reasoning tied to prior knowledge or lived experience. The excerpt below illustrates how resistance functioned as a productive and generative part of the engineering process:

Child 5:	Where is the other piece? The other part you wanted to put here?	
Child 6:	I've got a shadow!	*Connected*
Child 5:	No.	*Resistance*
	I don't think that will work	*Resistance*

	this side can’t go here	
	it has to be all the way down to the ground	*Novelty*
Child 6:	Careful	*Connected*
	we almost made Penny hot	
Child 4:	To get in there	
Child 6:	We need shadows for Penny	*Connected*
Child 7:	Not yet	*Resistance*
	not there	
Child 6:	[Child 2] what do we do now?	
Child 5:	Okay, sir	*Novelty*
	What about this?	
	Use this?	
Child 6:	AHHHHH!	
	Yes.	
	That would be a good choice	

Resistance was purposeful. This is highlighted by Child 7 saying, “Not yet”, implying a thoughtful response that indicated the proposed action did not align with the current stage of their process. Resistance did not derail the project or the design choices, it helped children refine their ideas. Some instances of resistance, like in the excerpt above, prompted shifts in direction of ideas and work, drawing the group’s attention toward alternative possibilities. In other cases, work briefly paused as children explored alternative lines of reasoning or tried new possibilities. For example, when Child 6 said “No. Guys, hold on. This right here, do this…” the design process and engineering were paused to entertain a new idea. Only a few times did the resistance move the project seemingly backwards. In these cases, the resistance was purposeful action to undo a decision or take an idea apart. This was illustrated by Child 1 when they said, “Wait, stop, stop. We can’t do that. We could take that apart…” Even actions that appeared to reverse progress (e.g., dismantling part of the structure) functioned as intentional moves toward refinement and improvement.

Resistance created tension which, in turn, sometimes sparkled deliberation. Although these moments slowed the immediate flow of activity, they also gave rise to new understandings or revised ideas. These actions did not impeded creativity; instead, they revealed children’s active, critical engagement with both the design task and their peers. Rather than just complying with peer suggestions, children actively shaped how the work unfolded. Such forms of resistance and critical collaboration are overlooked in interpretations of young children’s design activity. Through these interactions, children positioned themselves as evaluators and decision-makers who actively shaped the direction of the design work. Productive design work, in these cases, involved not only proposing ideas but also weighing alternatives. Design progress depended om moments when children collectively interrogated, reshaped, or set aside prior ideas. This positioned critical creativity as a driving force in the engineering process.

Discussion

When viewed through a sociocultural lens of resistance, the findings from this study position resistance as a meaningful and productive form of participation for young children in collaborative engineering design (Rainio, 2008). Rather than functioning as defiance or disruption, resistance emerged as an interactional resource for children as they questioned their peers' suggestions, delayed decisions, rejected other's proposed solutions, and engaged in practices central to engineering, including evaluating constraints, testing assumptions, and reconsidering how materials and structures function (Cunningham & Kelly, 2017). In this way, resistance became a visible mechanism through which the young children exercised agency within the group, shaping both the social and intellectual trajectory of the process (Litvinaitė, 2022).

Resistance was closely tied to several engineering habits of mind (Lillard et al., 2019), particularly creativity, optimism, and systems thinking. When the children resisted an idea (i.e., saying "not yet", pausing construction, proposing to take something apart) they often did so in response to perceived misalignments between a design choice and the problem at hand. These moments required the children to hold the design goal in mind, anticipate consequences, and advocate for alternatives that were more functional or aesthetically pleasing – practices that align with iterative and evaluative dimensions of engineering thinking (Cunningham & Kelly, 2017; Moore et al., 2018). Rather than completely halting progress, resistance slowed the pace of work in productive ways – creating space for deliberation, justification, and new ideas or thinking (Perumal, 2008). In these cases, resistance functioned as a form of collective sensemaking, enabling children to cooperate on thoughtful and intentional design choices.

Resistance also shaped the social dynamics of collaboration. Moments of pushback redistributed authority within groups, positioning children as both idea generators and as evaluators and co-directors of the design work. This aligns with the literature that conceptualizes resistance as a site for the negotiation of norms and where participation can be redefined (Perumal, 2008; Rainio, 2008). In early childhood engineering contexts, this kind of negotiation can support deeper engagement with both peers and materials. In turn, this allows young children to assert their perspectives, test boundaries, and contribute to shared and co-created solutions (Stetsenko & Ho, 2018).

Conclusion

This study contributes to early childhood engineering education by reframing resistance as an integral component of creative and collaborative design work. By attending closely to young children's talk during an engineering task, we highlighted how resistance can generate productive tension that has the ability to advance reasoning, support engineering habits of mind and ways of thinking, and deepen collective problem-solving and sensemaking. Moments of disagreement, hesitation, or pushback in young children's collaborative work do not always signal disengagement and conflict. Instead, these can be moments of engagement and possibility. Creating learning environments that allow space for children to exercise resistance by questioning ideas, slowing decisions, or revising plans, may support more authentic engineering practices and honour children as capable, thoughtful contributors to shared work. Attending more closely to resistance opens new possibilities for theorizing creativity in early childhood engineering as a socially negotiated process shaped by tension, critique, and collective decision-making.

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Learning The 5Rs To Promote Citizen Science In Primary Schools

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This study presents the development and validation of a Waste Manual based on the 5Rs (Reduce, Redistribute, Reuse, Recycle, Recover), designed to promote citizen science in primary education. The Manual integrates community involvement by offering a practical guide for teachers, parents, and guardians to foster environmental awareness and critical thinking in students. Aligned with Montessori principles, it emphasizes autonomy and active learning, encouraging students to develop skills for responsible decision-making. By engaging in structured activities, children learn to understand the environmental, social, and personal impact of waste management practices, fostering both individual responsibility and collective action. The pedagogical approach of the Manual incorporates levels of mastery adapted from Miller's framework, guiding students through progressively complex tasks that build their competence in applying the 5Rs. These activities also align with Bruner's spiral curriculum, ensuring that concepts are revisited and expanded upon to deepen understanding. The Manual encourages critical and creative thinking as central components for developing scientific literacy and fostering a long-term commitment to sustainable behaviours. The validation process involved eight experienced educators, each with advanced degrees and extensive teaching backgrounds, who analysed the Manual using a detailed questionnaire. Early results indicated its effectiveness in enhancing students' grasp of the 5Rs while also supporting their intellectual autonomy. Teachers highlighted the Manual's practical design, relevance, and potential to transform science education by linking theory with real-world environmental challenges. This paper explores the design process, the theoretical underpinnings, and the implications for advancing citizen science and sustainability education in primary schools.

Keywords: Citizen science, urban solid waste, Montessori.

Introduction

Primary education curricula highlight the importance of fostering environmental awareness and critical thinking. Despite differing approaches, they share the goal of equipping children with the skills to understand their environment and reflect on their actions, aligning with the broader aim of cultivating informed and responsible citizens.

This study addresses the integration of environmental education into primary schools through citizen science as a pedagogical framework. Specifically, it examines how the 5Rs (Reduce, Redistribute, Reuse, Recycle, Recover) can develop competencies in sustainable waste management and scientific literacy. The guiding research question is: How can we foster critical and active citizen science in primary school students? To explore this, a Waste Manual was developed to help teachers, parents, and guardians facilitate engaging activities centred on the 5Rs.

The Manual combines critical thinking principles, adapted from Miller's framework, with Montessori pedagogy, emphasizing autonomy and hands-on learning.

It aims to teach students the environmental impacts of waste while empowering them to take informed actions. By integrating theory with practice, the Manual seeks to instill lifelong habits of responsibility and scientific inquiry. This paper outlines the Manual’s development, its activities, and validation by expert educators, demonstrating its potential as a transformative educational tool.

The Montessori Methodology For Citizen Science Learning

The Montessori methodology provides a robust framework for fostering critical thinking and active learning, essential for developing scientific literacy and promoting citizen science. This approach emphasizes hands-on experiences and autonomy, encouraging children to explore, experiment, and reflect meaningfully on their actions. Central to this framework is the concept that mistakes are opportunities for growth, fostering self-esteem, confidence, and intellectual autonomy—key for addressing complex environmental challenges.

Citizen science within the 5Rs framework requires students to acquire scientific knowledge and apply it to real-world scenarios. Montessori pedagogy supports this by offering authentic learning experiences that connect students with their immediate environment. Research highlights that grounding education in tangible, local experiences enhance understanding, retention, and a sense of responsibility toward sustainability (Reis, 2021; Kowasch et al., 2021; García, Reis, Vásquez, 2022).

By integrating Montessori principles, the 5Rs Waste Manual empowers students to progressively develop critical thinking skills, aligned with levels of mastery adapted from Miller’s framework. Structured activities foster observation, analysis, and reflection, deepening students’ understanding of waste management and its societal implications. This holistic approach equips students to act responsibly within their communities and contributes to broader environmental and scientific initiatives.

Mastering The 5Rs In Primary Education

Developing competencies for solid waste management requires a progressive approach, especially in primary education. The 5Rs provide a framework aligned with Miller’s levels of mastery (1990), adapted by Albareda et al. (2019). As shown in **Table 1**, students’ progress from basic understanding (*knows*) to autonomous action (*does*), fostering critical thinking and practical application.

Table 1. Levels of mastery of competences through the development of critical thinking skills for science education.

LEVELS OF SKILL DOMAINING (Adapted from Miller, 1990)	CRITICAL THINKING (Prado, Junyent and Oliveras, 2022)
Knows	Understanding, Analysis
Knows how	Valuation, Inference
Shows	Explanation, Approach to context
Does	Self-regulation, Intellectual autonomy

Prado, Junyent, and Oliveras (2022) emphasize critical thinking as central to achieving these competencies. Structured around the 5Rs, activities guide students from recognizing waste issues (*knows*), to proposing solutions (*shows*), and implementing actions (*does*). This iterative learning aligns with Bruner's spiral curriculum (1960), which revisits concepts with increasing complexity.

By mastering the 5Rs, students connect personal actions to societal impacts, gaining scientific literacy, autonomy, and responsibility essential for sustainability and active citizenship.

Developing A Spiral To Learn The 5Rs

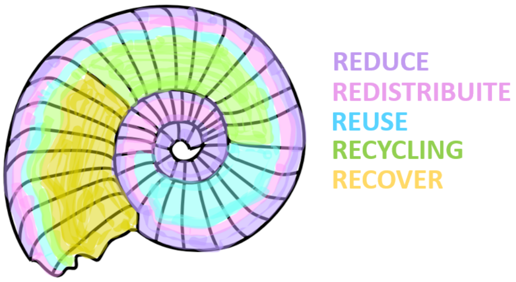
The spiral curriculum, proposed by Bruner (1960), introduces concepts at basic levels and revisits them with increasing complexity. This approach is particularly effective for teaching the 5Rs, as illustrated in Figure 1, were iterative learning fosters progressive understanding and application of waste management. Each R addresses a key aspect of waste management:

- Reduce: Avoid unnecessary consumption and minimize waste at the source.
- Redistribute: Sort waste to enable reuse, recycling, or recovery.
- Reuse: Extend product life through repurposing.
- Recycle: Transform materials into resources, reducing raw material use.
- Recover: Extract value from waste, such as nutrients or energy.

As shown in Figure 1, students revisit these Rs at increasing levels of complexity. For example, reducing waste begins with identifying unnecessary items (knows), progresses to evaluating bulk purchasing alternatives (knows how), leads to strategy design (shows), and culminates in real-world implementation (does). This progression mirrors Miller's levels of mastery (Table 1) and integrates critical thinking skills.

This iterative framework evolves with students, embedding critical thinking into activities, as highlighted by Prado, Junyent, and Oliveras (2022). It empowers learners to connect personal actions to societal and environmental impacts, fostering scientific literacy, autonomy, and responsibility.

Figure 1. Adapting Bruner's spiral for learning the 5Rs



Methodology

This study adopts a qualitative methodology to develop a Manual for solid waste management based on the 5Rs. The Manual combines playful and educational activities for each R, fostering engagement and learning. Its primary goal is to support teachers in promoting citizen science through a structured framework for environmental education.

Designed for both classroom and informal use, the Manual enables parents or guardians to participate alongside children, creating opportunities for collaboration and shared learning. This dual approach reinforces community involvement and encourages both children and adults to reflect on their waste management practices, fostering a collective commitment to sustainability.

Development Of A 5R Learning Manual

The 5R Learning Manual provides a structured yet flexible framework for teaching solid waste management to primary school students. It emphasizes practical, hands-on activities aligned with children's cognitive and developmental needs. The Manual includes clear objectives, detailed instructions, expected outcomes, and necessary materials to support effective learning.

Activities follow Miller's levels of mastery (Table 1), progressing from foundational knowledge (knows) to intellectual autonomy (does), fostering critical thinking and practical skills.

For instance, in the Reduce category (Table 2), activities like "Buy fresh and local products to reduce more" help students identify packaging types, consider bulk purchasing, and reflect on zero-waste principles through puzzles and reflections. These activities connect individual health with environmental sustainability.

The Manual supports both autonomous and guided learning, offering contextualized introductions, step-by-step methodologies, and reusable materials to reinforce resource efficiency. Its design ensures practicality for classroom and informal use, enabling parents or guardians to actively participate, fostering collaboration and shared responsibility.

By integrating critical thinking and sustainability principles, as proposed by Prado, Junyent, and Oliveras (2022), the Manual empowers students to connect personal actions to societal and environmental impacts. Following the spiral approach, activities build progressively, cultivating autonomy, reflection, and lifelong responsibility.

Table 2. Excerpt from the general structure of the 5R Manual.

5R	ACTIVITIES	OBJECTIVES AND METHODOLOGY
Reduce	Buy fresh and local products to reduce more	Through the cards and dates provided in the Manual, students learn to recognize different types of food packaging and reflect on how to reduce its use and volume. They are also encouraged to consider bulk purchasing to align with the zero-waste philosophy and complete a food pyramid puzzle to emphasize how individual health connects with sustainability and environmental health.
	Food Pyramid	
	Without packaging, like our grandparents did!	
	Reduce your waste to zero!	

5R Manual Validation Process

The validation of the 5R Learning Manual is a multi-stage process designed to ensure its effectiveness and relevance in fostering environmental education and critical thinking among primary school students. This paper focuses on the first two stages: the development of the Manual and its evaluation by expert educators. Subsequent stages, including practical classroom implementation and focus group analysis, will be addressed in future work.

The initial evaluation involved eight science teachers with extensive professional experience (a minimum of six years) and advanced academic qualifications (two Bachelor's, two Master's, and four Doctorate degrees). The teachers reviewed the Manual and completed a detailed questionnaire designed to assess its quality and applicability. The questionnaire consisted of 20 items across six key dimensions:

1. Writing: Clarity, readability, and coherence of the Manual's content.
2. Relevance: Alignment of activities with the needs and developmental levels of primary school students.
3. Use of materials: Feasibility and accessibility of the resources required for the activities.
4. Objectives: Coherence between the stated objectives and the proposed activities.
5. Autonomy: Ability of the activities to promote independent learning among students.
6. Critical and creative thinking: Effectiveness in fostering higher-order thinking skills.

Responses were measured using a 5-level Likert scale, ranging from “strongly disagree” to “strongly agree.” Teachers who rated any item a 3 or below were asked to provide detailed feedback for improvement. This additional input ensured a robust and iterative refinement process for the Manual.

Preliminary results from this evaluation indicate that the Manual is well-structured and effective in achieving its intended objectives. Teachers highlighted the clarity of the writing, the relevance of the activities, and the appropriateness of the materials. They also suggested integrating a unifying narrative or theme to further enhance student engagement and motivation, such as a story with challenges that link the activities cohesively. These insights will guide future iterations of the Manual to ensure its continued effectiveness and adaptability in various educational contexts.

Results And Discussion

The validation process of the 5R Manual involved an in-depth evaluation by eight expert teachers, who provided feedback on six critical dimensions of its design and applicability. Key findings are summarized below:

1. Writing: The Manual’s content was praised for its clarity, conciseness, and accessibility for teachers, parents, and guardians. Respondents noted its balance between scientific rigor and accessibility, ensuring relevance across diverse contexts.
2. Relevance: Activities were deemed appropriate for primary students and aligned with their developmental needs. Teachers valued the real-world connections and suggested additional complementary exercises to enhance the Manual’s scope.
3. Use of materials: The resources required for the activities were practical, easily obtainable, and simple to handle. This accessibility was noted as a strength, reducing barriers to implementation.
4. Objectives: The stated objectives were coherent with the activities and effectively guided intended learning outcomes, fostering critical and creative thinking.
5. Autonomy: Activities were effective in promoting independent learning while maintaining a balance between guided and autonomous tasks, allowing students to develop self-regulation and decision-making skills.
6. Critical and creative thinking: The Manual was recognized as a valuable tool for fostering higher-order thinking skills. Teachers suggested adding a unifying narrative or theme to further motivate students and contextualize the activities.

Overall, feedback reinforced the Manual's effectiveness as an educational tool, highlighting its potential to meaningfully engage students in sustainability education. These insights will inform iterative improvements to ensure the Manual continues to meet the needs of educators and students.

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“The Living Things In Our Schoolyard”: Design Of A Teaching-Learning Sequence For Primary Education

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The study of living beings and their classification is part of the curriculum in Primary Education. However, its study is often disconnected from the study of the relationships of interdependence between living beings and their habitats or problems associated with the loss of biodiversity. Therefore, in accordance with most Primary Education curricula, it is important that students acquire a general understanding of the organization of living things and their interaction with its environment, along with knowledge about local ecosystems and the services they provide. In that sense, many proposals and teaching materials to learn about biodiversity in primary education are available, but there is a pressing need to evaluate the potential of the naturalized school grounds to promote a deep understanding of this concept. We present a proposal for the design of a teaching-learning sequence (TLS) about biodiversity using the school's green space and its habitats. This proposal follows a Design-Based Research (DBR) methodology, because it offers an iterative process of design, implementation, evaluation and refinement, in an attempt to get a specific product - in our case a TLS - explicitly based on research results. We present results derived from the design phase using the DBR methodology, which involved the analysis of the school context through qualitative observational data from a pilot implementation in a 4th year primary classroom, definition of learning objectives and learning demands, to sketch a TLS about biodiversity in Primary Education.

Keywords: Teaching Learning Sequences, Biodiversity, Habitat, Primary Education, Ecodependence

Introduction

Biodiversity loss, one of today's most urgent socio-environmental crises, is closely linked to the growing disconnection between people—particularly children—and the natural world, which hinders the development of ecological understanding and the acquisition of knowledge about biodiversity and ecosystems that underpins sustainable lifestyles (Lindemann-Matthies, 2005; Lindemann-Matthies & Hyseni, 2009; Barrutia et al., 2022). Within Primary Education, the scientific model of living beings is a core curricular concept whose effective teaching benefits from the study of familiar animal and plant species in students' everyday environments and from direct, place-based experiences that enhance interest, connection with nature and understanding of environmental complexity (Willard, 2014; Gómez-Galindo et al., 2007). In this context, school green spaces—vegetated areas within school grounds, including school gardens and other outdoor learning environments—constitute authentic educational settings, comparable to classrooms or laboratories, with demonstrated potential to foster meaningful learning, well-being and community health and to contribute to competence-based learning and ecosocial resilience (Williams & Dixon, 2013; Chiumento et al., 2018; Eugenio-Gozalbo et al., 2019; Rammou et al., 2024; Aragón & Erdozain, 2025). There is thus a need for teachers to become familiar with these environments and with pedagogical approaches that leverage their potential, such as guided inquiry, which structures oriented research activities that reproduce essential aspects of scientific practice and position the instructor as mediator of learning rather than transmitter of knowledge (Rivero et al., 2011; Grossman, 2018). The integration of guided inquiry within school gardens enables learners to encounter biodiversity as a living, evolving reality, linking abstract ecological concepts to direct empirical experience and supporting conceptual change and the development of ecological literacy in real contexts (Eugenio-Gozalbo & Ortega-Cubero, 2024; Ayotte-Beaudet et al., 2025; Doychinova, 2023).

With this in mind, we propose a Teaching-Learning Sequence (TLS) for Primary Education contextualized in the habitats of a school green space, developed within a Design-Based Research (DBR) framework in which TLSs function both as research interventions and curriculum products, refined through iterative cycles of design, implementation, evaluation and redesign to address students' learning difficulties and local contextual characteristics (Méheut & Psillos, 2004; Juuti & Lavonen, 2006; Guisasola et al., 2023). The contribution reported in this paper focuses on the Design phase, in which we analyse the school context, conduct an epistemological analysis of biodiversity and habitats, and define learning goals and associated learning demands—understood as the gap between intended objectives and students' prior ideas—while adding a distinctive element: the contextual analysis is complemented by qualitative evaluation of a draft TLS, including pilot implementation of selected activities in the school green space, to inform the refinement of design tools, teaching strategies and learning trajectories before full implementation (Barab & Squire, 2004; Leach & Scott, 2002).

Method

The Design-Based Research (DBR) methodology for Teaching-Learning Sequences (TLSs) comprises three general phases: i) Design, ii) Teaching experiments, and iii) Retrospective analysis (evaluation and refinement of the TLS) (Guisasola et al., 2023). In this paper, we focus exclusively on the Design phase.

Contextual Analysis Through A Pilot Implementation

The research team designed and organised the TLS around an initial scenario that asks whether students can mention at least five organisms living in the school green space. From this scenario, a set of driving questions was developed to address three key ideas: 1) diversity of living things, 2) living things and their habitats, and 3) eco-dependent humans. A preliminary version of the TLS, adapted from a sequence originally designed in the context of pre-service primary teacher education (Rico et al., 2026), was piloted with a 4th-year primary class, focusing on key ideas 1 and 2, to gather contextual implementation data. This contextual analysis was conducted through external observation by the third author and focused on (a) implementation constraints (clarity of activities, time allocation, pedagogical feasibility) and (b) learning constraints (students' difficulties) (Coronel-Gastiain et al., 2025). Data sources included the observer's notes from each session and notes from post-implementation meetings with the primary school teachers, where practical challenges were discussed. These implementation and learning constraints (educational, material or scientific), which may limit students' learning (Kariotoglou, 2003), were used, together with other DBR tools, to design and tailor the TLS to 4th-year primary students.

Definition of Learning Objectives and identification of Learning Demands

The definition of learning objectives is a central step in TLS design. In our case, three elements were considered: i) analysis of the Primary Education curriculum, ii) a literature review focused on learning difficulties related to biodiversity and ecosystems at this level, and iii) an epistemological analysis of the concept of biodiversity and its relevance. The analysis of the school context determines the conditions under which the TLS will be implemented; beyond curriculum standards, it includes students' feedback and socio-cultural characteristics of the setting, which is essential when comparing results across schools or countries and responds to calls to better specify contextual factors in TLS design and evaluation (Cobb et al., 2003). The TLS is intended for implementation from the 4th year of Primary Education onwards, whenever biodiversity and ecosystems are addressed in the curriculum.

An epistemological analysis of biodiversity—which examines both its historical development and current scientific models and theories (Chu et al., 2021)—allows us to define learning goals (LG) grounded in disciplinary epistemology rather than school tradition. This is crucial both for evaluating students' achievement and for obtaining valid evidence on TLS effectiveness. The second key element is the analysis of the gap between these LG and students' typical learning difficulties, as identified in the literature. These learning demands are understood as the ontological and epistemic distance between students' ideas and the scientific concepts, and they guide the organisation of the TLS by indicating the type and degree of difficulty that students are expected to encounter. Larger learning demands require more specific and sustained instructional support (e.g., more activities, scaffolding), whereas smaller demands can be addressed with fewer or less intensive interventions (Guisasola et al., 2023; Ruiz-González et al, 2025).

The designed TLS, "Our school's biodiversity", proposes an experiential approach to biodiversity through guided inquiry in the school green space. Starting from students' initial models of living beings, students sample the different habitats in a naturalised area of the school to investigate its biodiversity. The design is structured around: i) Driving Questions (DQ) linked to the key ideas about biodiversity, ii) LG associated with each DQ and set of activities, which guide students towards constructing explanations for each key idea (Guisasola et al., 2023), and iii) the scientific procedures to be carried out by students. Learners work in collaborative groups and record their observations and reasoning in a student workbook, which also serves as a data source for subsequent phases of the DBR cycle.

Results And Discussion

Observed Constraints In The Pilot Implementation

A series of selected activities was piloted in a 4th year PE classroom in 2024, where the topic of living things and ecosystems was being taught. These practical activities were directed towards the examination and sampling of different habitats in a park near the school and a visit to the university organic garden at the end of the sequence (Figure 1). The implementation was carried out during the third term, between April and June in parallel with the classroom instruction on ecosystems conducted by the Primary Education teachers. This pilot version comprised a total of seven activities. Figure 1 (next page) presents the overall structure of the proposed sequence.

Based on the data obtained from the qualitative tools, such as the external observer's report and post-implementation meeting notes, we identified several constraints in the pilot, mostly in the material and the scientific domain (Kariotoglou et al., 2003). For example, students could predict some of the living things that could be found in their schoolyard or nearby park, but they could not depict their particular habitat, and this hindered the subsequent sampling activity. These scientific constraints also informed the definition of some learning demands, as we will show in the following section. A clear material constraint was the consideration that going outside was not a cooperative academic task, and 4th year students struggled to understand that field sampling involves a set of particular rules and procedures. A summary of constraints identified in the implementation for two activities and design decisions are shown in Table 1.

Epistemological Analysis And Definition Of Learning Goals

This pilot implementation informed the sketch and design of a TLS specifically targeted to Primary Education children. As stated in methodology, the proposed TLS was designed based on the epistemological analysis of the concept of biodiversity by looking at both its historical development, and current models and theories that allow scientific explanations about biodiversity (Chu et al., 2021).

Figure 1. Sequence of the activities

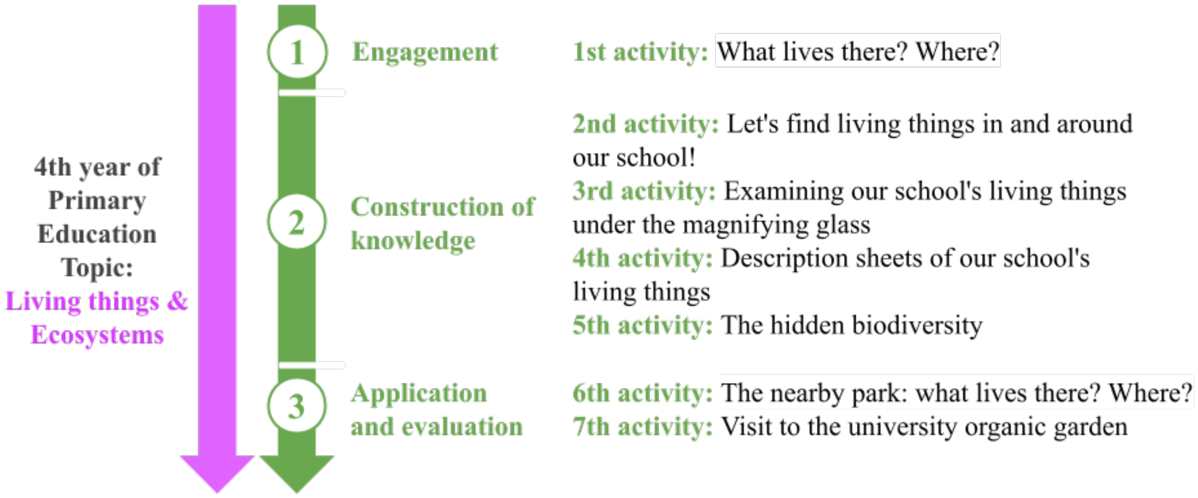

Table 1. Designed decisions based on observed constraints found in two activities of the pilot implementation.

Example of activities	Observed constraints	Design decision
Detecting student's initial ideas What lives there? Where?	Students can enumerate living things, but they have difficulties predicting where each one can be found. Although some examples were given, students were not able to represent the "habitat".	When covering the topic of living things and its classification, the concept of habitat must be explicitly taught.
Guided inquiry activity Let's find living things in and around our school!	Students show plant awareness disparity and do not consider them worth collecting or registering. Rule abiding and collaborative work while collecting data proved to be difficult.	Include a dedicated session to plant identification. Introduce students to the methods of sampling and data collection in a controlled space before exploring wider areas such as parks.

Biodiversity encompasses the variety of living organisms at genetic, species, and ecosystem levels, as defined by the Convention on Biological Diversity (United Nations, 1992), and includes not only species richness but also their relative abundance and functional roles within ecosystems (e.g., producers, consumers, decomposers) that enhance ecosystem resilience (Campbell et al., 2020). For 9-10-year-old children, this epistemology translates into five key learning goals aligned with primary curriculum standards: E1) recognizing millions of different living things with varying similarities; E2) grouping them by shared characteristics; E3) understanding species populations in specific habitats with suitable conditions for survival; E4) appreciating human well-being's dependence on other living beings and environments; and E5) identifying human impacts like habitat destruction, pollution, overexploitation, invasive species, population pressure, and climate change that threaten biodiversity (Campbell et al., 2020; Millennium Ecosystem Assessment, 2005; Willard, 2014). This focused framing grounds TLS design in disciplinary knowledge while addressing children's learning demands, such as scaling from observable school habitats to global concepts and normative conservation values (Navarro-Perez & Tidball, 2012).

The definition of our learning goals (see Table 2) is anchored in this epistemological analysis, instead of relying on textbooks or particular teaching styles (Guisasola et al., 2023). These indicators are measurable and will form the basis of specific open-ended questionnaires and teaching strategies to evaluate students' learning.

Table 2. Learning goals that define the concept of biodiversity and habitats in a TLS for Primary Education.

Elements from the epistemology of biology	Learning goals
E1. There are millions of different living things on Earth, some are very similar to each other, while others are very different.	**LG1.** To understand that there are many kinds of living things
E2. Living things can be classified into different groups based on their shared characteristics and features.	**LG2.** To learn to classify living beings into different groups according to their characteristics. **LG2.1.** To learn to distinguish and classify different types of animals. **LG2.2.** To learn to distinguish and classify different types of plants.
E3. Populations of particular species live in a specific place, which is called a habitat. The physical conditions and resources of the habitat must ensure the survival and reproduction of such a population.	**LG3.** To understand that there are different habitats at different scales according to physical conditions. **LG4.** To understand the connection between living beings and specific habitats and that changes in those habitats affect the organisms living there. **LG4.1.** To know which living things live in the immediate environment.
E4. Our well-being depends on the well-being of other living beings and the environment.	**LG5.** To understand the benefits or contributions that biodiversity (nature) offers to people. **LG6.** To understand that humans depend on nature (eco-dependency)
E5. Human activities have negative consequences on biodiversity due to: i) excessive human population; ii) overexploitation of natural resources; iii) habitat destruction, iv) pollution; v) introduction of invasive species and vi) climate change.	**LG7.** To know the impacts that humans have on nature and understand that we have the ability to influence it both positively and negatively.

Table 3. Alignment of Learning Difficulties with Learning Goals and identification of Learning Demands for a TLS about biodiversity in Primary Education

Learning difficulties	Learning demands	Learning Goal

Difficulties in distinguishing between living and non-living beings (Driver et al., 1994).	Low	LG1
Difficulty of naming taxons, other than mammals (Lindemann-Matthies, 2005).	Medium	
Plant and native species awareness disparity (Barrutia et al., 2022).	High	
Anthropocentric thinking (domestic, farming, cultivated,..) (Coronel-Gastiain et al., 2025)	Low	
Difficulties in biological classification skills and use of keys (Lindemann-Matthies, 2005).	High	LG2
Limited knowledge about habitats makes it difficult to relate a specific living being to a habitat (Marulcu, 2014; Savvaidou-Kambouropoulou & Skoumios, 2012)	Medium	LG3 LG4
Ignoring that biodiversity provides us with benefits other than material ones (e.g. regulatory services) (Rodriguez-Loinaz et al., 2022).	Medium	LG5
Lack of understanding of the normative dimension of biodiversity for conservation measures (Lindemann-Matthies et al., 2009).	High	
Lack of awareness of the importance of biodiversity in the health of the planet and people (Menzel & Bögeholz, 2009).	Medium	LG6
Lack of criteria to decide on effective measures for improving biodiversity (Rammou et al., 2024).	High	O7
Lack of perception of the consequences of daily decisions (good or bad) on local biodiversity (Rammou et al., 2024).	High	

Table 3 shows an example on how the definition of learning goals and the identification of learning difficulties allows for the identification of our student's expected learning demands. This is a pre-requisite to design appropriate teaching strategies, activities and evaluation tools. Primary students commonly struggle to distinguish living from non-living beings at an early age (Driver et al., 1994) and show limited recognition of plant and native species beyond familiar mammals, reflecting persistent biodiversity awareness disparities (Lindemann-Matthies, 2005; Barrutia et al., 2022). They often exhibit anthropocentric biases favoring domesticated species, face challenges in biological classification and using identification keys (Lindemann-Matthies, 2005), and struggle to link organisms to specific habitats due to limited ecological knowledge (Marulcu, 2014). Additionally, they overlook non-material ecosystem services, fail to grasp biodiversity's normative conservation dimension (Lindemann-Matthies et al., 2009; Torkar & Krašovec, 2019), and lack awareness of how daily decisions impact local biodiversity or criteria for effective conservation measures (Rammou et al., 2024). Despite these challenges, Primary Education students show high engagement and rapid learning when studying living things and nature through hands-on, inquiry-based activities in familiar contexts like school gardens, where they exhibit greater motivation, curiosity, and science achievement compared to traditional classroom settings (Dillon et al., 2006; Randler, 2008). Table 3 illustrates how these documented learning difficulties align with our learning goals to determine the corresponding level of learning demands (Leach & Scott, 2002).

Conclusion

We have presented an application of the DBR methodology for designing a TLS about biodiversity contextualized in the school green space for Primary Education, which will form the basis of a broader research program validating evidence-based TLSs in primary science education. A key novelty of this work lies in the contextual analysis conducted through pilot implementation of selected activities transposed and adapted from a TLS originally designed for pre-service primary teachers (Rico et al., 2026). This preliminary testing with 4th-year students provided critical data on implementation constraints (activity clarity, timing, feasibility) and learning obstacles, enabling us to tailor the TLS more precisely to primary learners' needs and school realities before full-scale development. As stated previously, the early DBR phases anchor the TLS robustly by integrating epistemological analysis of biodiversity, curriculum requirements, and documented learning difficulties from the literature. Further work involves defining instructional strategies to foster biodiversity understanding, while subsequent phases will evaluate the sequence's quality and learning outcomes to refine the TLS and generate empirical evidence on primary students' conceptual grasp of biodiversity, its ecological significance, and the impact of school green space interventions.

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Bridging Classical And Modern Physics: An Integrated Astronomy Curriculum For Primary Schools

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General Relativity, despite its central role in contemporary science, remains largely absent from school education. At the same time, research in science education shows that traditional instruction often fails to promote deep conceptual restructuring, leading to the persistence of misconceptions, particularly in astronomy. This paper presents an experimental study in physics and astronomy education that investigates whether integrating core principles of General Relativity into an astronomy curriculum can support the development of scientific competences. The intervention, conducted in Italian primary school, included activities focused on spatial reasoning and the use of reference frames, followed by the introduction of the basic ideas of light and gravity from a relativistic perspective. Data analysis is currently ongoing. The study discusses the potential of this approach to contribute to the renewal of science curricula.

Keywords: astronomy education, primary school, Einsteinian physics.

Introduction

In science, models play a central role in shaping how phenomena are interpreted and explained. Since the epistemological transformations of the early twentieth century, science has increasingly been understood not as a linear accumulation of empirical data, but as a coherent theoretical system grounded in conceptual models that guide observation, experimentation, and meaning making (Kuhn, 1962; Geymonat, 1972). From this perspective, empirical evidence cannot be separated from the theoretical framework in which it is embedded, as all observation is inherently theory-laden (Hanson, 1958). The formulation of General Relativity in 1915 represented a major paradigm shift in the understanding of space, time, and gravity, profoundly reshaping the scientific image of the world (Cassirer, 2015). Despite its foundational role in modern physics and cosmology, this theory remains marginal in compulsory schooling. In particular, astronomy education continues to rely mainly on classical models, with limited attention to the epistemological implications of modern physics.

At the same time, research on science learning has long documented the persistence of intuitive conceptions that are resistant to formal instruction, highlighting the limitations of traditional teaching practices in fostering deep conceptual change (Ausubel, 1968; Driver & Easley, 1978; Novak, 1987; Trumper, 2000). In astronomy education, these difficulties are especially pronounced and affect both students and teachers, contributing to low levels of conceptual understanding and to disengagement from the discipline (Atwood & Atwood, 1996). Current theoretical interpretations of these learning challenges are mainly framed within the Knowledge in Pieces Theory (diSessa, 2018) and the Framework Theory (Vosniadou, 2019). However, empirical studies explicitly examining how the adoption of different scientific models influences learning processes and the construction of a view of the universe remain scarce (Plummer et al., 2015).

Considering this context, physics education requires a non-hierarchical integration of epistemological, cognitive, and instructional dimensions (Gagliardi & Giordano, 2018). From this perspective, the present study investigates whether and to what extent the introduction of selected core concepts of General Relativity can support learning and motivation in primary school. Situated at the intersection of physics education research and educational science, the study designs and implements instructional sequences in fifth-grade classrooms, embedded within a broader astronomy curriculum conceived as an epistemic context for constructing meanings consistent with a modern physical–cosmological perspective. The study is currently ongoing, and data analysis has not yet been completed; therefore, this paper focuses on presenting the research design and the structure of the experimental intervention, which is part of a broader ongoing study.

Research In Astronomy And Physics Education

Research in the field of science education has long demonstrated that the practice of science teaching is frequently characterised by fragmentation and a lack of coherence. The pedagogical approach is typically predicated on linear and cumulative models, which are observed to have difficulty in reflecting the intricacies inherent in the learning process (Adams & Slater, 2000). In response to these limitations, numerous studies have emphasised the necessity to reconsider instructional design, commencing from Big Ideas, which are defined as conceptual macro-structures with the capacity to integrate and interpret a broad array of phenomena, situations and problems, thereby furnishing a unifying explanatory framework for comprehending the natural world (Plummer, 2012). Despite the absence of a unifying definition of a Big Idea in the extant literature, the various classifications proposed do align in acknowledging their role in the organisation of science instruction (Slater & Slater, 2009; Lelliott & Rollnick, 2010).

Big Ideas are closely connected to Learning Progressions, which are theoretical models that describe learning trajectories characterised by increasingly sophisticated levels of understanding. These models are grounded in empirical evidence on students' conceptual development (Rogat et al., 2011). Rather than representing a simple incremental accumulation of knowledge, these models aim to depict qualitative transformations in understanding, accompanied by increasing cognitive and epistemological complexity (ibid.). From this perspective, big ideas and learning progressions can be interpreted as complementary components of the same curricular structure: the former function as core conceptual nodes, while the latter outline the trajectories through which these nodes are progressively reorganised and deepened over time.

Despite the theoretical relevance of this framework, the literature highlights persistent difficulties in translating such models into coherent curricular designs, particularly with regard to the teaching of modern physics and astronomy concepts. In addition to theoretical contributions, a considerable number of instructional interventions focusing on specific physical and astronomical subjects have been developed. However, as Plummer et al. (2015) have noted, a perspective that systematically investigates the connections among these aspects within a coherent, progressive and long-term view of astronomy learning is still lacking. This limitation renders it challenging to ascertain the extent to which the adopted theoretical models influence learning processes and the construction of a coherent scientific view of the universe.

Within this context, the present study builds on two main strands of research. The first concerns the study of the apparent motions of celestial bodies, with particular reference to the experimental work of J. Plummer, who proposed a Learning Progression model in this domain. The secondary strand encompasses studies that are oriented towards the integration of contemporary physics and non-Euclidian geometry within educational settings. Among the most relevant initiatives is the Einstein First project, developed at the University of Western Australia, which has led to a vertical curriculum implemented in approximately sixty schools, from early childhood education to upper secondary school, integrating selected concepts of modern physics (Blair & Kersting, 2021; Popkova et al., 2021; Foppoli et al., 2018; Kaur et al., 2017, 2023; Choudhary et al. 2022). Complementary contributions are provided by the research of Kersting (2019; 2021) in secondary education and by the instructional experiments conducted by Gambini (2021) in primary school, aimed at introducing Euclidean and non-Euclidean geometry in an integrated and parallel manner from the early years of schooling.

While the extant studies reviewed here provide relevant contributions to the field, there is a need for further methodological refinement and greater attention to the transferability of results across different contexts.

Research Questions

In this framework, there is a necessity to develop studies that combine greater methodological robustness with a more systemic approach to disciplinary content. This would be capable of enhancing the conceptual and curricular integration of the different dimensions of astronomical and physical knowledge. In this study, the objective is to examine the hypothesis that integrating classical and modern paradigms in teaching can facilitate the development of scientific skills. This aspect represents one of the dimensions explored within a broader research project. Specifically, the hypothesis is that the systematic introduction of Einsteinian physics principles within an astronomy curriculum from primary school onwards has the potential to enhance students' scientific competence.

The research therefore aims to answer the following questions: i) In what ways does the learning of astronomy vary in relation to a curriculum that is more or less structured and integrated with Einsteinian physics principles? ii) What are the effects in terms of learning in socio-economically disadvantaged student groups? iii) What exogenous factors influence the achievement of these objectives?

The objectives of the research can thus be stated as follows: i)Analyse the impact of integrating Einsteinian physics into the teaching of astronomy on improving science skills; ii) Investigate the relationship between learning and the ESCS (*Economic, Social and Cultural Status*) indicator; iii) Investigate the impact on teacher training; iv) Contribute to the delineation of Learning Progress in the field of General Relativity.

Method

In view of the theoretical framework that has been presented and the necessity for further in-depth research, it was decided to adopt a quasi-experimental design with quantitative and qualitative data collection. On the one hand, the quantitative approach engenders results that are statistically stable and extends the conclusions to a broader context. Conversely, the integration of qualitative data facilitates the capture of the intricacies, variability and distinctive characteristics of the individual experimental groups and students involved, thereby circumventing an excessive reduction in the richness of information that is characteristic of educational experiences. A qualitative analysis is also necessary given the exploratory nature of research in the field of modern physics teaching in primary schools.

Three public primary schools in the Turin urban area were selected with average, medium-low and low ESCS indicators, based on the reports of the individual schools for the last two school years. The sample was selected on the basis of the research objectives, namely to investigate the relationship between the development of scientific skills and the ESCS indicator; therefore, it is not a random sample, but a reasoned one. The project was presented to three different public schools and was aimed at 4th and 5th grade classes, specifying the number of experimental groups required for each school. Participation in the project was voluntary. Four classes were selected for each school, corresponding to four experimental groups, for a total of 12 experimental groups and N=255 students. In particular, the following groups were established:

- G1: group in which a complete intervention by the researcher was tested in the 5th year primary class during the first term (complete group 1);
- G2: group in which a complete intervention by the researcher was tested starting from the 4th year primary class (complete group 2);
- G3: group in which the 5th grade class followed the teacher's educational programme and the researcher carried out a series of sporadic interventions during the first term (*spot* group);
- G4: control group.

Four experimental groups were created to analyse changes in variables based on different teaching choices. Firstly, a time frame similar to that usually adopted in Italian schools was utilised, i.e. condensing the teaching of astronomy into approximately five months of Year 5 primary school. This choice was linked to the availability of the teachers themselves. Concurrently, it was necessary to understand how learning varies when the teaching intervention is presented before the fifth year of primary school. The findings of research in this area indicate that there is no age below which it is impossible to introduce scientific teaching, on condition that it is calibrated according to the level of complexity that the child can manage (Levrini & Fantini, 2013). Consequently, the G2 group was identified, and the intervention was initiated in Year 4. These activities focused on the development of the necessary prerequisites related to the apparent motions of celestial bodies, as a basis on which to build future learning starting in Year 5 of the following school year.

Lastly, the G3 group was introduced, named “spot” for being a group in which the researcher carried out sporadic interventions in the classroom, in order to compare how learning varied between a complete curriculum, in which elements of classical and modern physics were integrated within the course, and a traditional one, conducted entirely by the teacher, in which the external specialist inserted himself and superimposed some activities specifically related to General Relativity. The choice adopted responds to the need to assess the effectiveness and transferability of short-term teaching interventions carried out by non-school personnel, a typology that is now widespread in the contemporary Italian school context. The division into experimental groups allows a comparative analysis of the outcomes, taking into account the differences between the experimental interventions and the socio-economic (ESCS) and gender characteristics of the participants.

An in-depth study on teacher training was planned to analyse the perceptions of the teachers involved and understand how they attributed meaning to the teaching experience, exploring how the proposal was integrated into professional practice and its contribution to the development of shared skills in the school community.

Knowledge And Skills Involved In The Curriculum

Following the operationalisation of the construct of scientific competence on the basis of international literature, the fundamental conceptual nodes of the curriculum were identified and developed. The experiment employed the Pedagogical Content Knowledge (PCK) model in an attempt to integrate the following criteria: i) content knowledge; ii) curriculum knowledge; iii) knowledge of students' difficulties and misconceptions; iv) knowledge of learning assessment; v) knowledge of teaching strategies (Magnusson et al., 1999). The curriculum was then constructed on the basis of a selection of four Big Ideas from those proposed in the literature:

- *Apparent motions of the Sun, Moon and starry sky.* Based on Vosniadou's studies (Vosniadou, & Brewer, 1994) on the patterns of naïve knowledge possessed by children, Plummer (2012) points out that apparent motions represent the crucial conceptual node and fundamental prerequisite for any future learning of astronomy.

- *Dimensions and distances*. It is widely acknowledged that the comprehension of cosmic dimensions and scales constitutes a fundamental intellectual concept that is notoriously challenging to master, particularly during primary school education (Lelliot & Rollnick, 2010). Despite its relevance, this aspect receives little attention in school curricula and textbooks, with frequently present distorted representations of the Solar System (Testa et al., 2014). This fosters the development of misconceptions that often persist well into adulthood (ibid.).
- *Dynamic properties of planets*, in which the concept of gravity is directly involved. Several studies have examined the misconceptions held by children and adolescents about this phenomenon (Bar & Zinn, 1998; Baldy, 2007; Bar et al., 2016), particularly emphasizing a geocentric view that frames gravity as a phenomenon limited to the Earth. However, despite these contributions, research on gravity within astronomy education remains scarce, and the topic is still marginal in school curricula, likely because of its abstract character and the challenges associated with making it accessible in educational settings. In addition, the majority of existing studies focus on instruction grounded in the Newtonian framework. From this perspective, General Relativity remains among the least investigated topics in educational research (Blair & Kersting, 2021). Within the Big Ideas approach, gravity can therefore be addressed in schools not only through the Newtonian paradigm, but also by introducing elements of General Relativity. Didactic tools such as the *elastic sheet* model (Kaur et al., 2017), while limited, are particularly useful in making changes in gravitational attraction visible as a function of mass, orbital speed around a central body, and that body's capacity to dominate the surrounding space gravitationally.
- *Stars*, with emphasis on the difference between stars and planets. In this regard, the primary distinguishing factor between stars and planets is light, rather than the nuclear reactions characteristic of stars. The concept of light and its properties is of significant importance and merits particular attention from the earliest stages of education, particularly pre-school (Leone, 2020).

After translating the Big Ideas into specific learning objectives, these were integrated with key conceptual elements of General Relativity, which were also defined in relation to the same objectives. The conceptual elements identified as relevant included: (i) gravity, (ii) reference frames, (iii) light, and (iv) geometry on curved surfaces. These elements were then incorporated within the corresponding Big Ideas.

Research Instruments

The literature proposes several standardised instruments for the detection of conceptual understanding in science, such as concept inventories (Lindell, 2001; Bardar et al., 2006; Sadler et al., 2009). However, such instruments are limited with respect to the assessment of scientific competences, particularly in astronomy, as they are designed for secondary school and are predominantly performance-oriented and do not allow for the systematic investigation of attitudes and processes underlying competence (Allal, 1999). Similarly, large-scale surveys such as PISA and TIMSS (OECD, 2019; Mullis & Martin, 2023) do not consider astronomy as a stand-alone area of assessment.

This framework highlights a structural problem in the detection of scientific competences, understood as the integration of knowledge, processes and attitudes, in line with a view of science as evidence-based model building (Gagliardi & Giordano, 2018). Consequently, it became necessary to design a purpose-built assessment tool. Starting from the conceptual cores and the specific objectives identified, a semi-structured test was developed for the detection of knowledge and skills, integrated with Guilford's (1967) model of cognitive processes and flanked by qualitative instruments aimed at investigating attitudes, considered to be the foundations of competence in astronomy. Participant observation, the authentic task and an evaluation rubric inspired by Allal's (1999) criteria were used.

The analysis was further deepened through semi-structured interviews aimed at teachers, designed from the logbooks and conducted according to an inductive bottom-up approach (Birks & Mills, 2015), in order to integrate the data collected and bring out the meanings attributed to the teaching experience.

Limitations And Perspectives Of The Research

At present, no definitive conclusions can be drawn, as the study is still in the experimental phase and data collection is ongoing. Nevertheless, some preliminary considerations regarding the strengths and limitations of the research can be outlined. The intervention may represent a step toward an approach to astronomy education in Italian primary schools that is more consistent with the epistemology of science and with constructivist perspectives on learning. In contrast to current instructional practices, which in astronomy remain largely grounded in traditional models and often show limited effectiveness in supporting conceptual restructuring and the development of complex scientific competences, the present design explores alternative instructional pathways. At the same time, disciplinary didactics involves substantial methodological complexity, as it requires the integration of multiple dimensions, including epistemological aspects related to the structure of physical concepts, instructional and methodological choices concerning teaching strategies and activity sequences, and cognitive aspects related to students' intuitive conceptions and processes of conceptual change.

A relevant limitation concerns the assessment instruments adopted, which present constraints in terms of validity. The astronomy test was specifically developed for this study, and, due to limitations related to sample size and intervention duration, it was not possible to conduct a preliminary exploratory factor analysis to examine its latent structure. For this reason, quantitative analyses of test scores should be complemented by qualitative analyses of open-ended responses, allowing for comparisons between experimental groups in relation to the differentiated instructional conditions. From a data triangulation perspective, test results will need to be interpreted alongside qualitative evidence, such as systematic classroom observations, audio or video recordings, and students' written artefacts, in order to better capture the processual nature of learning and to situate students' responses within their instructional context.

An additional point of interest concerns the introduction of concepts, such as reference frames, that are not typically addressed systematically in primary school curricula. This offers an opportunity to explore how students engage with such concepts and how their initial intuitive conceptions may be reorganized through the proposed activities.

Finally, the scope and diversity of the collected data suggest the potential to inform future research on Learning Progressions related to apparent celestial motions and, more broadly, to support further investigations into concepts such as gravity, whose Learning Progressions have traditionally been framed within a Newtonian perspective. In this contribution, however, these issues are not examined analytically; rather, they are outlined as directions for subsequent work, particularly with respect to the integration of alternative theoretical models into instructional design and the investigation of students' cognitive processes through longitudinal and in-depth analyses.

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