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Early Childhood Science Education

Research Trends in Learning and Teaching

Edited by

Konstantinos Ravanis

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Editor

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About the Editor

Konstantinos Ravanis

Konstantinos Ravanis is a Professor in Physics Education at the University of Patras in Greece. He completed two undergraduate studies, in Physics and in Educational Sciences, at the University of Patras in Greece, completed his postgraduate studies in Science Education in the Université Paris VII-Denis Diderot and received his PhD degree in Physics Education from the Department of Educational Sciences and Early Childhood Education of the University of Patras. In 1988, K. Ravanis was appointed a "Special Scientist", and then he was elected at all levels of the academic hierarchy to achieve the title of Professor (2004) in the Department of Educational Sciences and Early Childhood Education of the University of Patras, specializing in "Didactics of Physics". He was an invited Professor in Université de Provence, Aix-Marseille Université, Universidad de Buenos Aires, Université de Bretagne Occidentale, University of Nicosia, and he received a research fellowship from the Jean Piaget Archives at the University of Geneva. K. Ravanis is the author of about 230 publications in scientific journals, collective editions and conference proceedings and he has been the supervisor of 14 Ph.D thesis. He is the author of three (3) books and he was the editor of two (2) collective scientific editions. K. Ravanis was director of the Division of Theoretical and Applied Pedagogies (2003–2008) and has been Chairman in the Department of Educational Sciences and Early Childhood Education (1999–2001, 2005–2006), Vice-Rector (2006–2010) and member of the Council Foundation (2014) of the University of Patras.

Preface to "Early Childhood Science Education: Research Trends in Learning and Teaching"

The issue of initiating children aged 4–8 years into the world of Physical and Biological Sciences has been an open question and a field of research and application in recent decades. Over time, disciplines such as Early Childhood Education, as well as various trends in Psychology dealing with learning and development and Science Education, have become interested in this issue, providing different perspectives and different presuppositions. Thus, a new interdisciplinary approach has gradually emerged, which, in recent years, has been known as "Early Childhood Science Education" (ECSE). However, the variety of theoretical, methodological and empirical choices, as well as the ever-expanding themes in the relevant research, create an extensive spectrum, where the rational treatment and classification of trends is a prerequisite for the epistemological constitution of a new field. This necessary discussion, which could lead to a commonly accepted framework or even common ground when searching, is weak or non-existent.

A number of factors could lead to this apparent lack of coherence and a common perspective that could be beneficial to Early Childhood Education. These include research production among the dispersion in theoretical orientations and the avoidance of grand syntheses, chaotic mechanisms of the circulation of ideas and the extreme isolationist and/or antagonistic tendencies created and conditioned by distributions of power and funding.

However, there are forces of synthesis, communication and mutual understanding, aiming to rationalise and coordinate the different trends in order to broaden the potential to achieve a positive impact on young children's approach to the world of natural sciences. This is exactly the direction of the Special Issue "Early Childhood Science Education: Research Trends in Learning and Teaching". This Issue attempts to capture traditional and contemporary ECSE research trends, allowing them to co-exist in a single framework. Indeed, as this research has broadened and deepened in recent years, the scattered research output is increasingly making its presence felt around the globe. Differences in scientific backgrounds and traditions, levels of research development, the social environment in which research teams operate, and often the particular orientation of researchers related to their studies, as well as their working context and preferences, play an important role.

This diversity was reflected at many levels as articles were submitted and approved by blind review, with a wide range of research choices, from researchers working in Australia, Chile, Cyprus, Greece, Italy, Mexico, Poland, Slovakia, Spain, Sweden, Switzerland, and the USA.

Four articles attempt to review general or specific parts of the overall field of ECSE and 13 articles present specific research. These papers use qualitative and sometimes quantitative approaches, and subjects aged between 3 and 9 years, touching on topics such as:

- Children's mental representations of phenomena in the natural world and scientific concepts;
- The study of the implementation and effectiveness of specific teaching activities related to curricula or activities focusing on specific characteristics of teaching processes, such as reasoning, explanation, communication, interaction or argumentation;
- The issue of the relevance of teachers working in Early Childhood Education to the Physical and Biological Sciences;
- The use of specialised teaching materials;
- The emergence of the issue of scientific skills;
- The highly contemporary issue of the differentiation and inclusion of children in the world of science;
- Important socio-scientific issues;

The role of family-related factors.

This wide range of studies covers almost the entire research field of "Early Childhood Science Education" and highlights both the relevance of more classical research topics and the interest in new and contemporary questions. It goes without saying that the presentation of this publication is not an attempt to close this major issue of the early education of young children, but rather to shed light on research issues related to a particular area of learning and teaching, which must be constantly renewed. This perspective allows for us to take an optimistic look at the systematic and rational introduction of young children to the world of Physical and Biological Sciences in ways that contribute to their balanced development and respect their childhood and their mental and emotional world. It also allows us to think about and pursue the creation of a scientific community that shares common theoretical tools, develops coordinated research efforts, and systemically illuminates the pathways through which young children in contemporary societies approach science.

I would like to thank all the authors who have worked hard to produce high-quality, excellent work.

I also owe thanks to MDPI Publications and the Editors of the *Education Science* journal for their trust and editors for their help and effective support throughout this process.

Konstantinos Ravanis
Editor

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Editorial

Research Trends and Development Perspectives in Early Childhood Science Education: An Overview

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Abstract: This article serves as a critical approach to both the emergence and the identity formation of Early Childhood Science Education (ECSE) as a new scientific field, consolidated within the association of certain research divisions of Early Childhood Education, various branches of Psychology dealing with learning, and of Science Education. Consequently, we present research trends, orientations, and currents in ECSE, such as the study of children's mental representations, the development of teaching activities, teachers' perspectives, the preparation of teaching materials, scientific skills, diversity and inclusive education, the influence of the family, etc. Finally, we formulate some concluding remarks on research perspectives and the epistemological formation of ECSE.

Keywords: Early Childhood Science Education; research trends

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1. Introduction

The field of research, development, and application known as "Early Childhood Science Education" (ECSE) gradually emerged from the osmosis of wider scientific fields, various dimensions of which silently intersected after the 1950s. Indeed, Early Childhood Education, Genetic, Cognitive, Developmental and Educational Psychology and Science Education, despite their clear epistemological delineation, or even entrenchment, gradually adopted common fields of study—a development largely attributed to the increasing interest in children's initiation to the natural world phenomena. It is certainly very difficult, if not impossible, to trace the beginning of this implicit process, or to make any sort of safe assumption in regards to the necessity, or even the mere interest of this new perspective. However, during the past few decades, a large number of research papers has been written, approaching a very wide spectrum of subjects and orientations. This variety, despite its indisputable interest, creates a complexity that obstructs the epistemological identification of ECSE. Consequently, this hinders the efforts to create adjustments that enable the approach and comprehension of different choices, and their rational treatment within the broader fields of research, pedagogical applications, and, possibly, political-educative options.

In this article, we attempt to illuminate different dimensions of this scientific field, aiming to contribute to a discussion, which could, in turn, lead to finding common ground. The rationale behind this undertaking is that the effort to pinpoint, discuss, and try to arbitrate between certain concessions stands as a prerequisite to the creation of both a coherent scientific community and a genuine scientific tradition.

2. The Emergence of the ECSE: A Study Plan

Based on the hypothesis that aspects of early childhood or preschool education, of different branches of Psychology studying the development of children's intellect and of Science Education coexist within the field of ECSE, there is interest in observing the troubled and contradictory trajectory of this convergence.

To begin with, the prominent currents of traditional Preschool Pedagogy have always maintained a stable interest in children's familiarization with nature. The creation of pathways that lead pedagogical activity to the discovery of the natural world underlines a consistent choice, which influenced the most important theoretical currents of the field, despite their differences [1–3]. However, as time passed, Preschool Pedagogy began to transform, both due to an internal process of maturation, but also due to the ever increasing societal expectations regarding the role of this institution. Thus, in lieu of a general study framework, relying on philosophical thinking as its main source of ideas, we gradually witness not only the emergence of a field characterized by the creation of theoretical constructs, but also the articulation of questions related to a broad spectrum of issues within daily school life. It becomes apparent that there exists a distance between theoretical constructs and real educational issues; such a distance is to be covered by the practice of scientific research, arguably a common occurrence in every maturing scientific area within Social Sciences. Thus, modern Early Childhood Education has inherited from Preschool Pedagogy a stable orientation towards the familiarization of children with the natural world. Simultaneously, the approach of questions through research has developed to be a widely accepted practice, within the relevant scientific community. The combination of these two realities led a section of the Early Childhood Education scientific community to the field of research, regarding questions relevant to activity planning and development, drawn from the world of Physical and Biological Sciences [4–6].

From a different perspective, the interest of various branches of Psychology in ECSE has largely pivoted around the systematic relationship between this field and child development. Indeed, given the fact that learning figures as the main research subject within the framework of ECSE, psychologists' interest towards this orientation seems almost self-evident. It is widely accepted that Piaget's work [7] as well as the work of the school of Genetic Epistemology [8] has been a driving force towards this direction. It is also known that the theoretical orientation of this school is epistemological, not psychological, since it strives toward the study of the epistemic subject's thought development, namely human thought, and not that of the psychological subject, namely the child within different learning environments. Nevertheless, psychological research oriented towards learning issues has been influenced both by the clinical methodology of approaches to children's thought, as well as by the very research data which has helped construct the major Piagetian theoretical construct [9,10]. Thus, a research current started to gradually develop on the conceptualization of the natural world during early childhood. The main subjects of this research were the depiction of children's mental representations, the comprehension of concepts and phenomena, learning support techniques and strategies, the study of cognitive transformations, and the importance of social interactions and of the cultural environment [11–15].

The establishment of the field of Science Education began in response to the general disquiet associated with serious problems in the teaching and learning of Physical and Biological Sciences. Reasonably, initial interest focused on teaching subjects such as Physics or Biology, while the first issues posed were laboratory teaching, or curriculum planning, namely questions relating to the configuration of the teaching subject. During these initial pursuits, students and teachers were, in a way, viewed as "constants" within the educational framework. However, the study of problems in teaching, combined with an interest on scholarly performance, is inevitably filtered through learning issues. Thus, the scientific community operating within this field, following a trajectory not without doubt, ambiguity, and oftentimes misunderstandings, began approaching Social Sciences relevant to education. In this course, Science Education was influenced by theories that study the developmental course of students' thoughts and recognize learning as a product of active cognitive construction, and not as a transmission of information and knowledge; indeed, these theories attribute cognitive transformations to educational, social, and cultural interactions [16,17]. Consequently, and to a great extent, Science Education research was reoriented from the teaching subject itself to the relationship of students' thought with it. What is more, it focused on the sum of human and material resources and elements that foster the comprehension of concepts and phenomena within the Sciences. Integral to this course was the gradual realization that difficulties in students' learning encountered in the context of secondary education develop over time and undoubtedly originate in Early Childhood Education. Therefore, the structural and functional integration of developmental perspectives into Science Education research planning redirected a small part of this research to the age group of 4–8 years old [18–20].

It becomes evident that, since Early Childhood Education, Psychology and Science Education converged in a common general framework, albeit through different pathways, the cooperation of researchers and the creation of research groups comprising members of all three fields have been inevitable.

Undoubtedly, we are outlining a course with many setbacks, and the lack of communication between researchers originating from different scientific traditions figures as one of the most prominent ones. Nevertheless, a broad research spectrum has already developed despite these difficulties; truly, despite a lack of homogeneity, common orientation or epistemological coordination, research produced has, in the broadest sense possible, contributed to the initiation of young children to the world of Physical and Biological Sciences. During the last few years, the research horizon has broadened to include Technology, Engineering, and Mathematics, an approach also known as STEM. Despite the above, this approach constitutes a particular research field, and requires a specialized discussion, as its epistemological outlook is truly different. Briefly examined, it underlines the affinity of different areas, indeed an issue that remains constantly open to discussion in ECSE.

3. Research Trends, Orientations, and Currents in ECSE

An effort to map a scientific area, developed without a stable course, theoretically heterogeneous, and lacking a common perspective that researchers can share, will undoubtedly have inherent weaknesses and possibly contradictions. As a consequence, in lieu of an epistemological analysis starting from ECSE's origins, the only possible route appears to be an ex post approach, which is primarily based on research subject matter. For example, in a paper analyzing a section of post-1990 Anglophone research on 0–6-year-old children's approach to the Sciences, O'Connor et al. [21] state that the number of research papers on children aged 0–3 years old is much smaller than the number on children aged 3–6 years old, and on which there exists a critical mass of studies already. As a result, the authors highlight the need to further and deepen the study of the cognitive processes for the approach of phenomena studied by the Sciences. The general parameters used to analyze the selected papers were the following: (a) the teaching of Science concepts (emphasizing pedagogical practices), (b) the product of Science concept formation (conceptual understanding and/or demonstrated capabilities), and (c) the development of Science concept formation over time. The findings of this analysis showcased strong and weak aspects of ECSE research, and suggested future research needs and perspectives.

This type of targeted analysis highlights the issue of searching for key trends in research. However, ex post approaches are necessarily limited to the selection of explicit or implicit criteria for approaching texts. The choices of key research trends made in this article are based on an analysis of relevant published texts found in the Google Scholar database over the last 5 years with quantitative criteria and qualitative parameters such as the ages of the research subjects, single or multi-topic research, reference to a STEM or purely Physical and Biological Sciences learning and teaching environment, the appearance of these articles in other databases (for example, Web of Science and Scopus), etc.

Following and operating within a framework such as the above, we will trace the main tendencies in ECSE research, some of which tend to show signs of maturity, while others are still in development.

3.1. The Mental Representations

Children's thought itself and, more specifically, their mental representations on Physical and Biological Sciences concepts and natural world phenomena constitute a significant research field [22–24]. The aforementioned epistemological variety (or rather ambiguity) frequently suggests that, in relevant bibliography, mental representations are presented as ideas, alternative conceptions, mental models, perceptions, misconceptions, etc. This use of terminology is due to, on the one hand, researchers' differences in terms of scientific tradition, while, on the other hand, a lack of interest or even denial to develop a conversation that could illuminate these differences. Regardless, the terms above are identical entities in children's thought and their distinct characteristics allow children to engage with and comprehend in unique ways the elements of the world of Physical and Biological Sciences. This constitutes a typical research subject in Science Education for primary and secondary school students, and is usually presented as an effort to map the difficulties leading to the divergence of mental representations from knowledge gained in school. The identification of these difficulties facilitate the planning of appropriate but necessary teaching interventions. When applied to early childhood years, this subject adopts additional forms, as in that particular developmental stage mental representations are influenced to a great extent by different intellectual dimensions such as language or the organization of rational thought.

For instance, in research conducted on 5–6 year-old children's mental representations on the concept of the propagation of sound, special stress was placed on whether children comprehend that sound is an entity propagated in space [25]. Thus, in individual discussions with children on the concept of sound itself, the subjective characteristics of sound, and the phenomenon of the production and propagation of sound, it became evident that a very small number of children comprehend sound as a spatially located entity, or the trajectory between source and receiver. The large majority of children associate sound with objects that create or receive sound. These findings are interpreted as difficulties in children's thought formation, which inhibit their treatment of the propagation of sound as the movement of a typical natural entity. However, this research highlights the potential to develop teaching activities to that end, given the fact that some children are already able to recognize sound as an entity in space.

The development of mental representations over time and through education is another important subject. This is particularly interesting because, based on individual research aims found in relevant studies, it is possible to ascertain whether, and under which circumstances, it is possible to achieve cognitive transformation. For example, the main characteristics of a developmental course were found in research studying the development of 5–10 year-old children's mental representations regarding the shape of the Earth; truly, children were found to initially construct in their thought the idea of a spherical Earth, and then proceed to conceive of the relationship between the Earth and the sun [26]. Furthermore, "the order of resolving cognitive problems was established. It was assumed that problem solving involves re-establishing the location of people and objects on the surface and their movement. It was found that children first solve the problem of how people move on Earth, then their location, as well as the location of clouds, the Sun at night and trees. Finally, children match the way a kicked ball moves on Earth and the phenomenon of nightfall" [26].

In addition, the factors through which it would be possible to correlate the configuration of mental representations is an especially timely subject. For example, in research on the approach of certain thermal phenomena, working with 4–6 year-old children, observations were made to record children's behavior, interests, and abilities. During interviews based on specialized tasks, it was recorded that preschool children do not use the word "heat" or interpret change using this concept, but can, nevertheless, correlate changes in water temperature with certain phenomena. Concurrently, it became clear "that interest in science and language comprehension are significantly related to children's understanding of thermal phenomena" [27].

3.2. The Teaching Activities

The planning and development of activities to familiarize young children with Physical and Biological Sciences constitute possibly the most significant field of research in ECSE. In this case, the multiplicity of approaches warrants certain schematizations, which inevitably inherit the drawbacks encountered during the categorization of related, but not identical entities. Thus, we can generally recognize two major sub-fields of relevant research: research on integrated teaching activities, and point-focused research, emphasizing on specific aspects or study objects.

3.2.1. Research on Integrated Teaching Activities

In this first sub-field, we can classify research emphasizing activities' general characteristics, namely their theoretical framework, their overall planning as well as their structural elements. Such an analysis recognized three distinct research currents and frameworks, respectively influenced by Piagetian Genetic Epistemology, sociocognitive, and sociocultural approaches [28,29]. Out of the three distinct types, Piagetian approaches are no longer current since they are limited in many ways, while sociocultural approaches have been developing the past few years and are in a generalized process of discovery. Conversely, the sociocognitive approach remains a strong framework within which, historically, various research currents have been planning and implementing special teaching interventions as well as studying their characteristics and effectiveness.

Therefore, in relevant bibliography, we encounter efforts to plan interventions aiming for cognitive progress, after first illuminating difficulties that children face [30]. Other studies are oriented towards the transition of children's thought from mental representations to precursor models, namely fixed stable forms of thinking compatible with school knowledge [31], and most work in this context is generally based on inquiry-based methods [32,33].

For instance, research carried out by Gerhátová et al. [34] engages with the understanding of the process of temperature measuring by 8–9 year-old students, using a curriculum of Inquiry-Based Learning activities. This is carried out through a process of group and individual "guided inquiry" using on-site and remote experiments as well as electronic study materials. Research data has shown that the learning results of these activities are significantly of better quality than the results of traditional teaching, because children were observed to develop a satisfactory conceptual understanding of temperature. What is more, within the framework of Inquiry-Based Learning, it assisted children in developing a particular interest in the process, engage in discussion and present their work.

Nevertheless, socio-cultural approaches have recently begun to grow in importance in ECSE research, both because there is an increase in empirical research publications and because they implement theoretical tools that reinvigorate teaching practices [35–38].

For instance, Christodoulakis et al. [39] study the ways in which the Vygotskian concept of "perezhivanie" is showcased and utilized, a concept which generally connects the affective aspects of children's activity with the cognitive and psychomotor aspects. After the analysis of different emphases and modes of reception regarding perezhivanie in various research, they approach the use of the concept with a focus on early childhood education. Analysis of the data collected from this research shows that the concept is applied in related but distinct theoretical frameworks, and contributes greatly to the comprehension of different modes of experiencing, the development of self-awareness and to the planning of innovative teaching methods. Starting from this approach, they highlight the importance of the turn towards affective aspects of learning, as well as the potential effects this can have on ECSE research, teaching, and instructor training.

3.2.2. Point-Focused Research

In the second sub-field, the issues approached are related to internal aspects of activities, such as reasoning, explanation, communication, interaction, argumentation, etc [40–42]. Thus, the study of specific structural and functional parameters of the organization, communication, and content of activities create a particular research field, with a micro-approach orientation.

For example, the aim of a particular research paper on 4–5 year-old children was the identification of the reasoning processes and representations that they develop regarding sound [43]. The analysis of the interviews that took place illuminated the intentionality, representations, sign-material expressions, inferences, and coordination rules in children' mental constructions. Data collected from this research show that children's interpretations, reasoning, and conclusions rely on the ability to create certain epistemic tools.

The matter of argumentation encountered in children's conversation with their peers or adults is approached within the same general framework. Indeed, it is viewed as important in understanding children's reasoning, as well as certain affective, cognitive, and social dimensions of their thought, in studying the ways in which children approach the natural and social environment and, finally, in facilitating learning and educational activities. For example, in research carried out with 3–5 year-old children, there was an effort to study difficulties in argument formation, during problem-solving activities aiming to construct certain mechanical contraptions, alongside the researcher [44]. This research scrutinizes the issues occurring in each argumentative episode, standpoints and arguments, argumentative structures, implicit premises connecting each argument to its standpoint, distribution of arguments among the participants, and persistence in arguments expanding the boundaries of interactions. The analysis of this research's findings exhibits that successful resolution of issues and children's self-perception of their competences have a positive impact in argument formation.

An equally important issue approached in this research sub-field is that regarding the explanations given by children on natural phenomena. For instance, in research carried out with 5–6 year-old children, the attempt was made to study children's interpretations concerning the burning of a candle in an inverted receptacle, in relation to those children's previous experiences [45]. The data analyzed here show that children tend to provide naturalistic explanations regarding combustion, which was interpreted as an indication that they are able to form relevant mental representations in their thought.

3.3. Teachers' Perspective on ECSE

The matter of approaching issues pertinent to teachers is significant both in ECSE specifically and in the broader spectrum of educational research as a whole. Indeed, questions such as basic training and learning, attitudes and beliefs or teaching practices among Early Childhood Education teachers in the Physical and Biological Sciences are always important. This holds true as they are clearly related to matters of quality and effectiveness in young children's education [46–49].

For example, research carried out by Zoupidis et al. [50], through the use of a specialized questionnaire, focused on kindergarten teachers' intentions to utilize in their teaching practice knowledge and teaching methods gained in a learning seminar. Research data analysis showed that these intentions are based on estimates regarding the teachers' own competence in implementing relevant activities. Furthermore, they are based on their own approximation of students' ability to learn in a meaningful manner. Last but not least, this research showcased that teachers' options are linked to a calculation of personal gain or loss, to the views held by important third parties, and to the stress placed on the traditions of Science Education or Early Childhood Education.

3.4. Teaching Material

Teaching materials generally constitute important tools in Science learning and in ECSE; so much so that they warrant a specialized and particular approach. Such materials are curricula and programs, specialized instruments utilized in the Sciences, mindfully selected everyday objects, specialized software and informational books, collections of activities, etc. Research in this thematic area is not well-developed and thus focuses lately on the latter categories of material, namely texts. The creation and use of multimodal material in which different types of representation and semiotic modes are combined, i.e., text, images, graphs, are treated as particularly significant [51–54].

For instance, relevant research focuses on " . . . verbal text-image relations in terms of the interpersonal meaning dimensions of address (the way the reader is addressed), social distance (the type of relationship between the reader and the represented participants), and engagement (the extent to which the reader engages with what is represented) in multimodal text extracts from science books for preschoolers" [55]. Research data collected on the concepts of "address", "involvement" and "social distance" were studied in terms of "complementarity", "divergence" and "convergence" relations. Based on their analysis, the researchers presented thoughts and hypotheses on the selection, creation and effective utilization of multimodal science texts for young children.

3.5. Contemporary Research Issues at ECSE

Lately research fields in Educational Sciences have begun to develop and reorient to new areas of study, which approach aspects of learning processes connected to "horizontal" issues in education. Indeed, these issues are related to children's initiation with the Sciences, but they also have a broader scope and are not exclusively tied to learning objectives. Thus, it is not uncommon to encounter issues in relevant bibliography such as socio-scientific questions, diversities, and inclusive education [56,57].

3.5.1. Scientific Skills

Research on scientific skills is based on the notion that human beings, in their effort to answer spontaneous questions on the way the world works, but also on every issue that requires reason as well as critical reflection, use types of thinking pathways that require the activation of certain mental tools. Within this framework, various scientific processes include skills such as quantity measurement, observation, classification and grading of items or properties, prediction, experimentation, hypothesizing, communication, etc.

For example, in research focusing on the development of nutritional competence in a class of students aged 4–5 years, a sequence of teaching units was designed and implemented "that focused on learning skills such as observing, measuring or interpreting data related to plants, their germination and growth, and its relation to the development of nutritional competence" [58]. This research's results showed that these activities motivated students to engage with the subject while also cultivating their interest and ability to take initiative. Last but not least, the researchers recorded a general inclination towards the Sciences, leading the students to develop nutritional competence.

The objective of another relevant research was to develop an observation tool for early childhood problem-solving skills and science and engineering knowledge [59]. This tool was implemented on multiple levels, and it provided the opportunity to record a large spectrum of observable behavior of 3–5 year-old children, within a wide timeframe, during which teachers were asked to teach their current science/STEM curriculum. The research findings showed that, through their participation in activities, subjects exhibit behaviors that verify the view that preschool children are indeed competent to meaningfully engage in problem-solving. Furthermore, the researchers recorded a correlation tendency between the duration and level of exposure children have to curricular activities, with the development of new vocabulary words.

3.5.2. Diversity and Inclusive Education

The last few decades an important issue has arisen across all levels of education—namely, the effort to secure equal opportunities and appropriate learning environments for students that are diverse in terms of gender, ethnicity, national origin, language, religion, disability, socioeconomic status, special needs, etc. Clearly, this sort of research has different orientations, despite its common general framework, due to the variety of its subjects. What is more, these concerns have recently appeared in the study of issues relating to the approach of the Sciences in Early Childhood Education [60,61].

For example, the study focus in research carried out with dual language learners 3–5 years-old was the importance of teachers' language use during instruction, of the language of assessment, and of language dominance when approaching the Sciences [62]. Therefore, "differences between the two languages were examined, then associations between performance on science assessments were compared and related to children's language dominance, teacher quantity of English and Spanish, and teachers' academic science language" [62]. The most significant research data showed that Spanish-dominant children had better results on Spanish science assessments, while differences in language use by teachers, namely Spanish or English, was apparently not pivotal. Nevertheless, while the use of high-quality Spanish vocabulary influenced children's performance in Science learning, the same was not observed when speaking English.

3.5.3. Socio-Scientific Issues

Modern economic, scientific, and technological development has proven to be the currency of new, important questions. These questions are labeled socio-scientific because they are socially relevant and real-world problems that are informed by science, and which are oftentimes controversial and include an ethical component [63]. Issues such as genetic testing, global warming, the use of nuclear energy, water pollution, and recycling, in correspondence with children's age, are essential in shaping informed, critically thinking citizens who adjust their views based on scientific data and are sensitive to the great issues humanity faces today. Such teaching approaches are hesitantly emerging in Early Childhood Education, emphasizing teacher training, even though the complexity of these subjects does not allow for a broad development [64,65].

For example, Ampartzaki et al. [66] present in their research a project that was realized in eight European countries in early-year settings, aiming to explore the relationship between water and human technological culture, from a sustainability perspective. In this project following a preparatory phase for both teachers and students, the researchers designed the search for a source of fresh water, and a subsequent visit to the site. During the visit, the participants collected information on the relationship of water to the natural and technological environment. This data was analyzed alongside the children and, based on the information collected, there was an effort to answer the initial set of questions. These activities were compiled in teachers' portfolios, which were then analyzed by the researchers. Subsequent analysis emphasized the existence of three types of application. The first type has descriptive and surface characteristics; the second type includes well-designed and interconnected activities based on research questions, while the third type adopts the main characteristics of the second type but includes references to children's social characteristics as well as the relationship of water to general human culture.

3.5.4. The Influence of the Family

Issues pertaining to Science learning and teaching are ordinarily approached within the framework of educational institutions, even regarding 3–8-year-old children. However, during the past few years and within a general tendency to showcase and study atypical and informal educational methods, we have witnessed the emergence of a new important dimension—namely, research on the potential role of the family in matters of familiarization with the Sciences, Technology, Engineering and Mathematics, that is to say, with fields also recognized in current bibliography as STEM. While this body of bibliography is not yet well-developed, relevant research papers have lately begun to proliferate [67].

In an effort to compile and document such papers, [68] studied relevant bibliography after 1995. The research findings analyzed show that STEM activities constitute a suitable framework, helping parents to recognize the value and importance behind these activities and to engage further with them, thus positively influencing STEM learning for preschoolers. What is more, it appears that parents are able to influence young children's interest and self-efficacy regarding STEM activities, facilitating their involvement with them. Finally, the researchers highlight the lack of research correlating parental influence with young children's involvement with STEM.

4. Concluding Remarks

The approach taken regarding the main research orientations realized shows that ECSE covers a broad study field, including matters of children's cognitive development, teaching personnel, and the configuration of suitable teaching objectives and practices. In this sense, it constitutes a distinct, albeit still developing, scientific framework.

Naturally, the shaping of a scientific tradition with a stable epistemological formation and commonly accepted structural elements, both internally and within the broader framework of Education Sciences, is a long process. This process presupposes the objective maturation of a broader need, and the recognition of this need from members of a scientific community which decide to enter a common, interdisciplinary theoretical and research space. In the current phase of ECSE development this process is slow and hesitant; the fact that, to this day, specialized conferences or journals have not have the opportunity to emerge is especially interesting, and indicative of a general lack of growth.

Nonetheless, the work done thus far, despite the drawbacks mentioned above, has created a common field of reference in research, or, to be more exact, a spectrum of research fields, the pivotal point of which is child-oriented approach to Physical and Biological Sciences. This course inevitably creates interdisciplinary research questions that stress the need for the convergence of different perspectives [20,28,57,69]. For instance, when the need arises for teaching activities regarding a specific natural phenomenon on a kindergarten level, we witness this convergence within a common study field; the process of tracing difficulties in children's thought studied by psychological research meets the processing and arrangement of subject matter studied by Science Education and the planning of pedagogical practices in the classroom studied by Preschool Education.

Indeed, the need for interdisciplinary options is proportionate to the complexity inherent to the connection of scientific traditions constituted within different traditions. Differences in terms of theoretical framework, methodological tradition, even variety in researcher's identities oftentimes lead to isolation or distancing, which is not conducive to the creation of environments of synthesis and common perspective. If the current level of research development and its application within the framework of ECSE exhibits a particular dynamic in individual fields, then one of the pressing matters for the near future is the creation of an integral research and application space, allowing for theoretical and methodological convergence, and the creation of a forum for common scientific expression. This process could help shape a unique epistemological identity for ECSE, the constitution of which could be structured based on widely accepted starting principles, shared between the participating traditions.

Development towards this direction could influence, to a certain extent, official curricula as it could create a distinct, internationally grounded reality, offering reliable solutions to the need of curriculum renewal, and of Early Childhood Education programs.

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education sciences

Review

Early Childhood Science Education from 0 to 6: A Literature Review

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Abstract: Over the past three decades, our understanding of science learning in early childhood has improved exponentially and today we have a strong empirically based understanding of science experiences for children aged three to six years. However, our understanding of science learning as it occurs for children from birth to three years, is limited. We do not know enough about how scientific thinking develops across the first years of life. Identifying what we do know about science experiences for our youngest learners within the birth to three period specifically, is critical. This paper reviews the literature, and for the first time includes children in the birth to three period. The results are contextualised through a broader review of early childhood science education for children aged from birth to six years. Findings illustrated that the empirical research on science concept formation in the early years, has focused primarily, on children aged three to six years. The tendency of research to examine the *process* of concept formation in the birth to three period is also highlighted. A lack of empirical understanding of science concept formation in children from birth to three is evident. The eminent need for research in science in infancy–toddlerhood is highlighted.

Keywords: science; early childhood; science education; literature review; concepts; infants; toddlers; preschoolers

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1. Introduction

We are living in times characterised by an explosion of scientific knowledge [1] and rapid rates of innovation in technology [2]. Globally, however, there exists a decreasing trend in student interest in science upon school completion [3] and in Australia, students' performance in science is declining [4]. It is now widely accepted that early science learning experiences are essential for the development of children's scientific knowledge and inquiry skills [5]. Appropriate scientific work can and should begin as early as possible for all children [5–7]. Concerningly, however, research has shown that current early years provisions fail to meet children's potential [8]; young children's science learning is not being systematically stimulated [9] and there are significantly fewer opportunities for young children to engage with science activities in comparison to other content areas [10]. In addition, many early childhood teachers feel discomfort when teaching sciences [11], and have expressed concern at the lack of appropriate pedagogical strategies [12,13]. The eminent need to provide more quality and challenging science experiences in early childhood is highlighted [8].

Reflecting increasing recognition of the ability of young children to engage in science learning [14–16] and the paramount significance of early science learning to later science outcomes [17], early childhood science education research as a distinct research field, has increased significantly over the past three decades [18]. Within the field, however, studies have focused predominantly on children aged three to six years with only a limited pool addressing science learning in the birth to three period specifically. Consequently, we have a strong, empirically based understanding of science experiences for children aged three to six years. In contrast, however, our understanding of science learning in infancy and toddlerhood, as it occurs for children from birth to three years, is limited.

Seeking to develop our understanding of a crucial yet largely unknown area of science education research, the current study aimed to review the empirical literature on science concept formation in the birth to three period (within the context of the wider early childhood science education literature). An empirical literature search was conducted over the period March 2020 to January 2021. Peer reviewed journal articles examining science concept formation in pre-school settings (birth to six years), from 1990 to date, were included. Findings illustrated that the empirical research on science concept formation in early childhood, has focused primarily on children aged three to six years (50 of 57 studies identified). A lack of empirical understanding of science concept formation as it occurs from birth to three was found.

This paper presents the findings of the literature review. An overview of the methodological framework used to conduct the literature review is firstly presented and the categorisation process used to discuss the studies identified, is outlined. Overall findings of the review are then depicted graphically (Figure 1) with individual characteristics of the included studies presented in Tables 3–5. Findings of the review are then discussed in accordance with the identified categories (a detailed explanation of which is later provided). For each category, a brief summary of the literature on children aged three to six years is firstly provided. This is then followed by a more in-depth discussion of the literature on children from birth to three years.

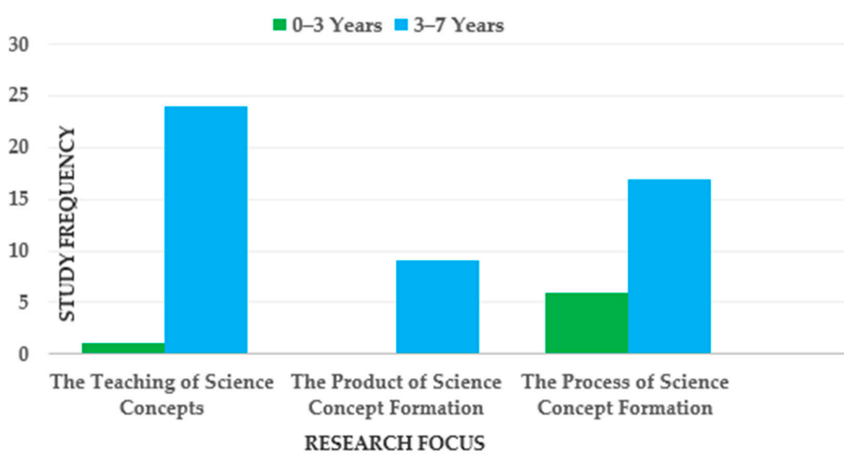

Figure 1. The Empirical Literature on Science Concept Formation in Early Childhood (Peer Reviewed International Journal Articles From 1990 to Date) by Research Focus and Participant Age.

2. Methodological Framework of the Literature Review

Reviewing to our knowledge, for the first time the empirical literature on science concept formation in the birth to three period specifically, this paper provides critical insight into our current understanding of science experiences of infants and toddlers. Gaps that exist in the literature regarding infant and toddlers' thinking in science are highlighted and the eminent need for research emphasised. The following subsections describe the methodological framework used to conduct the review.

2.1. Methods

An empirical literature search was conducted over the period March 2020 to January 2021 using the following databases: A+ education, ERIC, ProQuest education journals, PsycINFO and SCOPUS. Peer reviewed journal articles (written in English), examining science concept formation in the early years setting from 1990 to date, were included. Only studies examining science concept formation in pre-school age children were included. This differed in accordance with the age of formal school commencement across countries. Studies examining science concept formation within the broader context of Science, Technology, Engineering and Mathematics (STEM) or Science, Technology, Engineering, Art and Mathematics (STEAM), were excluded. Studies in which the overall research focus did not relate to concept formation and/or children's thinking in science, were also excluded. The inclusion and exclusion criteria are presented in Table 1.

Table 1. Literature search inclusion and exclusion criteria.

Category	Inclusion Criteria	Exclusion Criteria
Research Aim/Key Words	Studies focusing on science concept formation/children's "thinking" in science	Studies in which science *concept formation* was not of primary interest
Topic	Science	STEM/STEAM
Age	Pre-school age children (country dependent)	Children in formal schooling
Area	International	None
Time	1990 to date	Prior to 1990
Type	Peer reviewed journal articles	Books/book chapters/non-academic articles, editorials, conference proceedings
Language	English	None-English

Table 1 provides an understanding of the way in which studies were identified for inclusion in the literature review. The next subsection outlines the way in which the studies included, were categorised for the purpose of analysis.

2.2. Categorisation

The studies identified in the literature search were categorised into three groups according to the overall research focus; The Teaching of Science Concepts (Pedagogical Practices) (Category 1), The Product of Science Concept Formation (Conceptual Understandings/Demonstrated Capabilities) (Category 2) and The Process of Science Concept Formation (Development Over Time) (Category 3). A description of the categories and further sub-categorisation is now provided.

2.2.1. Category 1: The Teaching of Science Concepts (Pedagogical Practices)

Studies examining science concept formation in relation to pedagogical practices were grouped together and categorised; Category 1: The Teaching of Science Concepts (Pedagogical Practices). Studies were then further grouped into 2 sub-categories according to the more specific, research aim; studies exploring the effectiveness of specific teaching interventions/educational programs in relation to science concept formation (1A); studies exploring the effect of individual differences amongst educators in relation to science concept formation (1B).

2.2.2. Category 2: The Product of Science Concept Formation (Conceptual Understandings/Demonstrated Capabilities)

Studies that explored children's individual conceptual science understandings were grouped together and categorised; Category 2: The Product of Science Concept Formation (Conceptual Understandings/Demonstrated Capabilities). Studies were then further grouped into 2 sub-categories according to the more specific, research aim; studies exploring pre-school age children's conceptual understandings of science concepts (2A); studies exploring the age (biologically) that children begin developing scientific reasoning skills (2B).

2.2.3. Category 3: The Process of Science Concept Formation (Development over Time)

Studies that focused on examining the process of concept formation were grouped together and categorised; Category 3: The Process of Science Concept Formation (Development over Time). Studies were then further grouped into 2 sub-categories according to the more specific, research aim; studies seeking to explore and understand *how* children are developing their understandings of science concepts (3A); studies seeking to explore and understand the role the teacher plays in creating conditions for children developing conceptual understandings in science (3B).

Studies in Group 3A examine the *process* of science concept formation (how children are developing an understanding of science concepts over time). These studies differ to studies in Group 2A where the focus of research is on identifying children's conceptual understandings and/or ability to engage in science learning at a specific point in time.

Studies in Group 3B explore the way in which elements of the teachers' role influence the process of concept formation (how early childhood teachers create the conditions for the formation of science concepts). These studies therefore differ to studies in Category 1 (The Teaching of Science Concepts) where the focus of research is on examining the efficacy of specific teaching methods, interventions or instructional strategies in promoting scientific understanding.

Table 2 provides an overview of the categorisation. The frequency of papers by category and age of participants is also presented.

Table 2. Studies regarding science concept formation in early childhood published from 1990 to date by research aim and participant age.

Research Area	Research Focus	Frequency 3 to 7 Years	Frequency 0 to 3 Years
CATEGORY 1: The Teaching of Science Concepts (Pedagogical Practices)	To explore the effectiveness of specific teaching interventions/educational programs (in relation to science concept formation) (1A).	20	1
	To explore individual differences amongst teachers (in relation to science concept formation) (1B).	4	0
	Total Frequency:	24	1
CATEGORY 2: The Product of Science Concept Formation (Conceptual Understandings/Demonstrated Capabilities)	To explore pre-school age children's conceptual understandings of science concepts (2A)	7	0
	To explore the age (biologically) that children begin developing scientific reasoning skills (2B)	2	0
	Total Frequency:	9	0
CATEGORY 3: The Process of Science Concept Formation (Development Over Time)	To explore and understand *how* children are developing their understandings of science concepts (3A)	13	5
	To explore and understand the role the teacher plays in creating conditions for children developing conceptual understandings (3B)	4	1
	Total Frequency:	17	6
TOTAL (overall):		50	7

Table 2 presents the frequency of studies included in the review by categorisation according to the research focus and research aim. Table 2 shows that of the 57 studies identified for inclusion in the review, 50 related to children aged three to six years and 7 related to children in the birth to three period. Table 2 also illustrates that 25 studies examined science concept formation in relation to the teaching of science concepts (Category 1) of which 1 related to children in the birth to three period; 9 studies examined science concept formation in relation to the product of science concept formation (conceptual understandings/demonstrated capabilities) (Category 2), all of which involved children aged three to six years; 23 studies examined the process of science concept formation (Category 3), 6 of which related to children in the birth to three period.

3. Findings and Discussion

3.1. Individual Study Characteristics

A summary of the main characteristics of the studies included in the review are now presented in accordance with the categories discussed. Three different tables are presented. The first table (Table 3) summarises the main characteristics of studies in Category 1 (The Teaching of Science Concepts; Pedagogical Practices). The second table (Table 4) summarises the main characteristics of studies in Category 2 (The Product of Science Concept Formation; Conceptual Understandings/Demonstrated Capabilities). The third table (Table 5) summarises the main characteristics of studies in Category 3 (The Process of Science Concept Formation; Development over Time). Within each table, the studies are presented in alphabetical order of the author's names.

Table 3 presented the characteristics of empirical studies examining science concept formation in the early years (birth to six years) in relation to the teaching of science concepts (pedagogical practices). Table 4 now follows, presenting characteristics of empirical studies examining science concept formation in the early years (birth to six years) in relation to the product of science concept formation (conceptual understandings/demonstrated capabilities).

Table 4 presented the characteristics of empirical studies examining science concept formation in the early years (birth to six years) in relation to the product of science concept formation (conceptual understandings/demonstrated capabilities). Table 5 now follows, presenting characteristics of empirical studies examining science concept formation in the early years (birth to six years) in relation to the process of concept formation (development over time).

Table 5 presented the characteristics of empirical studies examining science concept formation in the early years (birth to six years) in relation to the process of concept formation (development over time).

Collectively, Tables 3–5 provide an overview of the general characteristics of studies which have examined science concept formation in the early years. A summary of the overall findings and ways in which science concept formation has been examined, from the studies included in the review is now provided.

3.2. Findings

The findings from the literature review of published empirical works on science concept formation in early childhood are illustrated through a bar graph of categories (Figure 1), followed by a discussion of what was determined through an analysis using the categories discussed; 1. The Teaching of Science Concepts (Pedagogical Practices); 2. The Product of Science Concept Formation (Conceptual Understandings/Demonstrated Capabilities), and 3. The Process of Science Concept Formation (Development over Time).

Figure 1 provides a visual representation of the empirical literature on science concept formation in early childhood by research focus and participant age. The extent with which research has involved children aged three to six years (in contrast to children in the birth to three period) is highlighted. 50 studies involved children aged three to six years, 7 studies related to children in the birth to three period. A limited empirical understanding of science experiences of children in the birth to three period (in contrast to that of older pre-school age children) is highlighted.

A discussion of the studies identified in the review is now provided by category. Having been previously reviewed the literature on children aged three to six years are firstly summarised and a more detailed discussion of studies involving children aged birth to three then given.

Table 3. Characteristics of empirical studies examining science concept formation in the early years (birth to six years) in relation to the teaching of science concepts (pedagogical practices).

Research Focus	Reference	Research Aim	Science Concept(s)/Skills	Country/Sample	Methods	Findings/Conclusions
To explore the effectiveness of specific teaching interventions/educational programs (in relation to science concept formation) (1A).	Dejonckheere et al., 2016 [19]	Tested and integrated the effects of an inquiry-based didactic method for preschool science.	Scientific reasoning skills	Belgium, 57 children aged 4 to 6 years	Structured interviews (pre-post-test)	The inquiry-based didactic method encouraged children's spontaneous exploratory activities.
	Dogru and Seker, 2012 [20]	To determine the effect of science "activities" on cognitive development and science concept acquisition skills.	Astronomy	Turkey, 48 children aged 5 to 6 years	Interviews, participant drawings	"Science activities" is an effective technique in the acquisition of basic concepts related to "the Earth, Sun and Moon".
	Hadzigeorgiou, 2002 [21]	Investigated the efficacy of structured hands-on activities to facilitate preschool children to construct the concept of mechanical stability.	Mechanical stability	Greece, 37 children, 4.5 to 6 years	Video recordings	Appropriately structured activities involving children's action on objects, complemented with a scaffolding strategy, help children construct the concept of mechanical stability.
	Hannust and Kikas, 2007 [22]	Analysed the influence of instruction on the development of astronomical knowledge.	Astronomy	Estonia, 113 children aged 5 to 7 years	Video recordings, interviews, drawing tasks	Children acquired factual information easily and over-generalized new knowledge easily: materials used in teaching may promote the development of non-scientific notions.
	Hong and Diamond, 2012 [23]	Examined the efficacy Responsive Teaching (RT) and the combination of Responsive Teaching and Explicit Instruction (RT + EI) to facilitate children's learning of science.	Floating/sinking, scientific problem-solving skills	United States America (USA), 104 children aged 4 to 5 years	Interviews (pre-post-test)	Children learned science concepts and vocabulary better when either responsive teaching or the combination of responsive teaching and explicit instruction was used.
	Kallery et al., 2009 [13]	Examined the extent to which the teaching practices adopted by early-years educators are successful in supporting young children's understanding in science.	Physics, biology, astronomy	Greece, 11 teachers	Field notes	The didactical activities analysed did not promote scientific understanding. Scientific activity was mainly confined to the representational level.
	Kalogiannakis et al., 2018 [24]	Examined whether the "picture story reading" method can be beneficial for young children learning about magnetism.	Magnetism	Greece, 30 children aged 4 to 5.5 years	Structured interviews, children's drawings	Pictorial story reading in kindergarten, together with suitable questions by the teacher were effective in aiding understanding of magnetism.
	Kambouri-Danos et al., 2019 [25]	Examined the way in which the construction of a precursor model can support children's scientific learning.	Water (change of states)	Greece, 91 children aged 5 to 6 years	Interviews	It is possible for children aged 5 to 6 years, to consistently approach a complete sequence of water state changes, as part of a specifically designed teaching intervention.

Table 3. *Cont.*

Research Focus	Reference	Research Aim	Science Concept(s)/Skills	Country/Sample	Methods	Findings/Conclusions
	Kolokouri, and Plakitsi, 2016 [26]	Examined the connection of Cultural Historical Activity Theory with Science Education in the early grades.	Light/shadows, colour	Greece, 92 "pre-primary" children	Video recordings, interviews, field notes	The learning of scientific concepts is a creative component of methods, interactions and social practices. CHAT is a promising field for Science Education in the early grades.
	* Lloyd et al., 2017 [27]	Developed and delivered a programme of activities aimed at encouraging parents' confidence in their own ability to support emergent scientific thinking.	Forces, materials and their properties, the living world	England, 19 care givers, 26 children aged 0 to 5 years	Audio recordings, questionnaires	Parental interaction enhanced children's learning at least as much, if not more, than practitioner interventions. Mediation of experience by familiar adults facilitated enjoyment, encouraged natural curiosity.
	Nayfeld et al., 2011 [28]	Developed an intervention to increase childrens use of science materials (in preschool classrooms) during "free choice" time.	Properties of matter	USA, 84 children aged 3 to 5 years	Time sampling method, interviews	Children's voluntary presence and exploration in the science area increased after the intervention. Children demonstrated improved conceptual knowledge.
	Peterson, 2009 [29]	Examined the use of narrative and paradigmatic modes of explanation in large group discussions about science in preschool classrooms.	Measurement, mapping, light, properties of matter, natural habitats	USA, 29 teachers, 479 pre-school children	Video recordings	Students in the "science curriculum" classrooms were exposed to a higher frequency of paradigmatic explanations and produced a higher relative frequency of paradigmatic explanations.
	Ravanis, 1994 [30]	Explored learning situations that take place within the framework of a constructivist pedagogy.	Magnetism	Greece, 79 children, mean age 5.5 years	Video recordings, field notes	Children were able to discover the action of attractive magnetic forces on nonmagnetic materials, the attractive and repulsive forces between magnets, and distinguish between magnetic and nonmagnetic material.
	Ravanis et al., 2004 [31]	Investigated the effect of a socio-cognitive teaching strategy on young children's understanding of friction.	Friction	Greece, 68 children aged 5 to 6 years	Structured interviews (pre-post-test)	Evidence for the effect of the socio-cognitive strategy on children's understanding of a "precursor model" for the concept of friction was found.

Table 3. *Cont.*

Research Focus	Reference	Research Aim	Science Concept(s)/Skills	Country/Sample	Methods	Findings/Conclusions
	Ravanis and Pantidos, 2008 [32]	Explored Piagetian and Post-Piagetian strategies for children working with magnets.	Magnetism, friction	Greece, 41 children aged 5.5 to 6.5 years	Video recordings	The differing educational content of the two pieces of research led to different levels of progress in children's thought. Successful changes in children's thought occurred only in the case of magnetic properties.
	Ravanis et al., 2013 [33]	Investigated the effect of a socio-cognitive teaching strategy on young children's understanding of light.	Light	Greece, 170 children aged 5.5 to 6.5 years	Structured interviews (pre-post-test)	Evidence for the effect of the socio- cognitive strategy on enhancing children in constructing a "precursor model" for the concept of light was found.
	Strouse and Ganea, 2016 [34]	Investigated whether adult prompting during the reading of an electronic book enhanced children's understanding of a biological concept.	Electricity	USA, 91 children aged 4 years	Structured interviews (pre-post-test)	Under some circumstances, electronic prompts built into touchscreen books can be as effective at supporting conceptual development as the same prompts provided by a co-reading adult.
	Tenenbaum et al., 2004 [35]	Investigated the effectiveness of a combined museum and classroom intervention project on science learning in low-income children.	Water related concepts	USA, 48 kindergarten children	Interviews	In general, the program supported children's science literacy development with regard to both concept complexity and content knowledge.
	Valanides et al., 2000 [36]	Investigated the effectiveness of a teaching intervention designed to teach pre-school age children astronomical concepts	Astronomical concepts	Greece, 33 children aged 5 to 6 years	Interviews	The majority of children accepted that the Sun and the Earth are separate spherical objects, but fewer children attributed the day/night cycle to rotation of the Earth on its axis.
	Walan and Enochsson, 2019 [37]	Explored the outcome of using a model in which drama and storytelling were connected to facilitate learning processes in science for young children.	Human biology (the immune system)	Sweden, 25 children aged 4 to 8 years	Semi structured interviews, drawings	The combination of storytelling and drama as an instructional strategy has a positive potential when it comes to teaching children science.
	Zacharia et al., 2012 [38]	Investigated whether physicality (actual and active touch of concrete material) is a necessity for science experimentation learning at the kindergarten level.	Balance	Cyprus, 80 children aged 5 years	Structured interviews (pre-post-test)	Physicality appears to be a prerequisite for students' understanding of concepts (concerning the use of a beam balance), only when the students have incorrect prior knowledge of what a beam balance does.

Table 3. *Cont.*

Research Focus	Reference	Research Aim	Science Concept(s)/Skills	Country/Sample	Methods	Findings/Conclusions
	Fleer, 2009a [39]	Examined teacher philosophy and pedagogical practices within the context of an analysis of children's concept formation within early childhood settings.	Water related concepts, properties of matter	Australia, 2 teachers, 24 children aged 4 to 5 years	Interviews, video recordings, photographic documentation	Teacher philosophy about how young children learn is a significant contributing factor to learning in science.
To explore individual differences amongst teachers (in relation to science concept formation) (1B).	Gerde et al., 2018 [40]	Investigated the nature of teachers' domain-specific self-efficacy.	Common science activities (early childhood science curricula)	USA, 67 teachers	Teacher surveys	Domain-specific self-efficacy was lower for science than literacy. Self-efficacy for science, related to teacher's frequency of engaging children in science instruction.
	Fleer et al., 2014 [41]	Examined how the environment is perceived by teachers for creating opportunities for science learning.	Common science activities (early childhood science curricula)	Australia, 65 children, 3.3 to 4.6 years	Video recordings, photographs	A "sciencing attitude" on the part of the teacher affords meaningful science learning for preschool children.
	Gomes and Fleer, 2018 [42]	Examined how teachers use the preschool environment to promote the teaching of science concepts.	Experiment based science activities	Australia, 2 pre-school teachers	Video recordings	Teachers in the same preschool setting have different levels of science awareness for the possibilities of informally teaching science.

* Studies examining science concept formation in the birth to three period.

Table 4. Characteristics of empirical studies examining science concept formation in the early years (birth to six years) in relation to the product of science concept formation (conceptual understandings/demonstrated capabilities).

Research Focus	Reference	Research Aim	Science Conept(s)/Skills	Country/ Sample	Methods	Findings/Conclusions
To explore pre-school age children's conceptual understandings of science concepts (2A).	Akerson et al., 2011 [43]	Examined the capability of young children to learn about the Nature of Science (NOS).	NOS	USA, 18 children; kindergarten to 2nd grade.	Structured interviews	Children improved their understandings of NOS in each setting. Kindergarten children are developmentally capable of conceptualizing NOS when it is taught to them.
	Allen, 2017 [44]	Explored aspects of pre-schoolers' ecological understandings.	Ecology	England, 70 children aged 3 to 5 years	Structured interviews	5-year-old children arecapable of grasping concepts inherent in food chain topics scheduled to appear later in their schooling.
	Borgeding and Raven, 2018 [45]	Investigated pre-schoolers understandings of fossils in the context of a week-long informal science camp.	Fossils	USA, 15 children aged 3 to 6 years	Structured interviews	Clear age and object-related trends for living/non-living distinctions, teleological reasoning, origins, and object ages were noted.

Table 4. *Cont.*

Research Focus	Reference	Research Aim	Science Conept(s)/Skills	Country/ Sample	Methods	Findings/Conclusions
	Constantinou et al., 2013 [46]	Examined the ability of young children to construct operational definitions in magnetism and the importance of scaffolding the learning environment.	Magnetism	Cyprus 165 children aged 4 to 6 years	Structured Interviews	Cognitive maturation is not the main determinant factor that shapes the performance pattern of these children. The necessary role of scaffolding the curriculum materials to achieve successful learning is highlighted.
	Forman, 2010 [47]	Explored the relations between young children's play and scientific thinking.	Push/pull, force, scientific thinking skills	USA 3 children aged 3 to 4 years	Video recordings	The small experiments, inventions, strategies, and pauses in young children's play reveal a legitimate form of scientific thinking. Science and play represent a frame of mind.
	Krnel et al., 2005 [48]	Explored the development of the concept of matter.	Matter	Slovenia, 84 children aged 3 to 13 years	Structured interviews	Young children (age 3 to 7 years) experience objects and substances by acting upon them or using them.
	Smolleck and Hershberger, 2011 [49]	Investigated the conceptions and misconceptions of young children related to science concepts, skills, and phenomena.	Matter, magnetism, density	USA, 63 children aged 3 to 8 years	Video recordings	Findings reveal the most common conceptions related to matter, magnetism, density, and air.
	Solomonidou and Kakana, 2000 [50]	Investigated the representations and primary notions children create, on the basis of their everyday experience, for common electrical devices and electric current.	Electricity	Greece, 38 children aged 5.5 to 6.5 years	Semi structured interviews	Children had no difficulty in recognising and naming the electric appliances they were familiar with. Children held a variety of preconceptions about electric current.
To explore the age (biologically) that children begin developing scientific reasoning skills (2B).	Piekny and Maehler, 2013 [51]	Investigated when scientific reasoning skills emerge and whether these abilities develop synchronously during childhood.	Scientific reasoning skills	Germany, 223 children, 4 to 13.5 years	Structured interviews	The three cognitive components of domain general scientific reasoning emerge asynchronously during early and middle childhood.
	Piekny et al., 2014 [52]	Investigated how and when children's ability to evaluate evidence and their understanding of experimentation develops, (between ages of 4 and 6).	Scientific reasoning skills	Germany, 138 children,4 to 6 years	Structured interviews	The ability to evaluate evidence is well developed at age four and increases steadily and significantly over time. Children's understanding of experimentation increases significantly between the ages of 5 and 6.

Table 5. Characteristics of Empirical Studies Examining Science Concept Formation in The Early Years (Birth to Six Years) in Relation to The Process of Concept Formation (development over time).

Research Focus	Reference	Research Aim	Science Concept(s)/Skills	Country/ Sample	Methods	Findings/Conclusions
To explore and understand *how* children are developing their understandings of science concepts (3A).	Christidou, and Hatzinikita, 2006 [53]	Explored the different types and characteristics of preschool children's explanations of plant growth and rain formation.	Natural phenomena	Greece, 60 children aged 4.5 to 6.5 years	Semi- structured interviews	Children are relatively selective in regard to the explanatory type they use when discussing natural phenomena. Naturalistic explanations have different characteristics according to the phenomenon under discussion.
	Fleer, 2009b [54]	Examined the reciprocity between everyday thinking and scientific thinking during playful encounters in early childhood centres.	Physical attributes of materials	Australia, 48 children 4 to 5 years (4 focus children)	Video recordings, photographs, interviews	Playful events provide an important conceptual space for the realisation of dialectical relations between everyday concepts and science concepts. The "teacher as mediator" is central.
	Fleer, 2013 [55]	Examined the emotional nature of scientific learning; affective imagination in early childhood science learning.	Heating/cooling, light	Australia, 53 children aged 3 to 4 years	Video recordings	Identify 5 key elements that draw attention to the relations between emotions and cognition in science learning.
	Fleer, 2019 [56]	Examined how imaginative play promotes scientific learning and how teachers engaged children in scientific play.	Microbes and Microscopic organisms	Australia, 3 pre-school teachers, 26 children aged 3.6 to 5.9 years	Video observations, photographs, interviews	The building of collective scientific narratives alongside of discourses of wondering were key determinants of science learning in play-based settings. The Scientific Playworlds is a possible model for teaching science in play-based settings.
	Fragkiadaki and Ravanis, 2014 [57]	Explore the dynamic of pre-schoolers' interactions during the approach of basic science concepts.	Natural Phenomena	Greece, 16 children aged 4 to 6 years	Open type, semi-structured conversations	Different types of substantial interactions between the children couples were identified. Through a "conversational approach", organized in couples, we can foster and enhance science thinking and learning in early childhood.
	Fragkiadaki and Ravanis, 2016 [58]	To structure a cultural-historical understanding on how early childhood children experience science and how they develop scientific thinking as they interact with the social, cultural and material world.	Natural phenomena	Greece, 1 childaged 5.2 years	Expanded, open-type conversations	Insights into how a certain social situation between children and educators in kindergarten settings becomes the unique social situation of a child's development was gained.

Table 5. *Cont.*

Research Focus	Reference	Research Aim	Science Concept(s)/Skills	Country/ Sample	Methods	Findings/Conclusions
	Fragkiadaki and Ravanis, 2015 [59]	Examined children's representations on the phenomena of the natural world and on natural science concepts.	Natural phenomena	Greece, 16 children aged 4.5 to 6 years	Expanded, open type conversations between children and researchers	Children use different types of representations dominated by the nature of the substance under study. Children possess a range of ideas and explanatory mechanisms regarding the natural phenomenon and they are able to reason about them.
	Fragkiadaki et al., 2019 [60]	Aimed to provide a cultural-historical understanding on how children form relevant representations of clouds as well as how children's understandings are transformed and developed through communications with others.	Natural phenomena	Greece, 16 children aged 4.5 to 6 years	Expanded, open-type conversations	When children construct everyday understandings of natural phenomenon, they draw upon multiple discussions, collaborations, social experiences, knowledge, practices, values, attitudes, tools, signs, objects, sketches, and gestures. Imagination is an important dimension of children's thinking.
	Fragkiadaki et al., 2021 [61]	Seek to capture and explore the dialectic interrelations between intellect, affect, and action during science experiences within early childhood educational settings.	Natural phenomena	Greece, 113 children aged 4.5 to 6.5 years	Video recordings (semi-structured conversations)	The findings made visible the processes through which children make sense and shape their understandings of the natural phenomenon during everyday educational reality.
	Fredj, 2019 [62]	Explored how science is done in collaborative interactions when children discuss reasons for animal diversity.	Animal biology	Sweden, 27 children aged 6 years	Video recordings	While engaged in highly collaborative interactions, the children use observations to evaluate, challenge and question each other. The character of the collaborative interactions is an important factor for how acts of doing science are carried out.
	* Klaar and Öhman, 2012 [63]	Explored how infants form science concepts through their actions in nature.	Natural phenomena	Sweden, 1 child aged 22 months	Video recordings Practical Epistemological Analysis (PEA)	Bodily experiences, (physical encounters) are fundamental for children's further learning about natural phenomena and processes. A methodology based on the principles of PEA allows for analyses of non-verbal, bodily actions in order to investigate toddler's physical nature experiences.

Table 5. *Cont.*

Research Focus	Reference	Research Aim	Science Concept(s)/Skills	Country/ Sample	Methods	Findings/Conclusions
	Larsson, 2013a [64]	To gain knowledge about what aspects of, and in what way, contextual and conceptual intersubjectivity contribute to emergent science knowledge about sound.	Sound	Sweden, 10 children aged 3–6 years	Video recordings, teacher transcripts	Emergent science knowledge is developed when it is enhanced by teachers' double move between conceptual and contextual intersubjectivity. The use of contextual and conceptual intersubjectivity contribute to bridging children's everyday understandings to scientific concepts.
	* Larsson, 2013b [65]	Explored preschool children's opportunities for learning about friction.	Friction	Sweden, 4 children aged 2.1 to 5.6 years	Video recordings; "shadowing"	Children are in contact with the phenomenon of friction during their play. Everyday play situations can be used by teachers to become more knowledgeable about children's understandings of the friction and direct their attention to it.
	* Sikder, 2015 [66]	Examined how sciene concept formation becomes part of the infants-toddlers lived everyday experience at home.	Force, water properties, heating/cooling.	Australia and Singapore 4 children aged 10 to 36 months	Video recordings, interviews	Children are learning concepts (or/and small science concepts) through the purposeful actions of parents. Possibilities of science concept formation at the infant-toddler age are not any extra effort for parents.
	* Sikder and Fleer, 2015 [67]	Examined social interactions in everyday family life that supports the development of science concepts for infants and toddlers.	Everyday science activities (family home)	Australia and Singapore 4 children aged 10 to 36 months	Video recordings, interviews	"Small science" can help explain how the everyday experiences of young children lay the foundation for the development of concrete "scientific" concepts.
	* Sikder and Fleer, 2018 [68]	Examined infant-toddler's development of science concept formation within the family context.	Everyday science activities (family home)	Australia and Singapore 4 children aged 10 to 36 months	Video recordings, interviews	Small science concepts can be developed through a special form of narrative collaboration, where parents and infants consciously consider the environment from a scientific perspective.
	Siry et al., 2012 [69]	Explore the nature of science learning as a social phenomenon that is discursively bound.	Water related concepts	Luxembourg, 29 children aged 4 to 6 years	Video recordings, children's photographs and paintings	By positioning scientific inquiry as a fluid process children were able to enact science collaboratively and through multimodal means.

Table 5. *Cont.*

Research Focus	Reference	Research Aim	Science Concept(s)/Skills	Country/ Sample	Methods	Findings/Conclusions
	Siry and Max, 2013 [70]	Examines how children enact developing understandings in science through multiple interactions.	Water related concepts	Luxembourg, 26 children aged 4 to 6 years, 1 teacher	Video recordings (researcher), video recordings and photography (children)	Children's investigations were mediated by their own speculations and explanations. Emphasis is placed on the value of students being positioned as co-constructors of science curricula.
	Abdo and Vidal Carulla, 2020 [71]	Explore emergent understanding of preschool-aged children about the scientific concept of "small", as used in theoretical chemistry.	Chemistry concepts	Sweden, 4 children aged 3 to 5 years	Video recordings	A process of "sustained shared thinking" could describe the teaching/learning processes evident in the children's and teacher's conversations. Sustained and shared conversations between children and teachers should stem from children's everyday experiences.
To explore and understand the role the educator plays in creating conditions for children developing conceptual understandings (3B).	*Fragkiadaki et al., 2020 [72]	Examined how infants in play-based settings, develop scientific understandings about their everyday world.	Sound	Australia, 13 children aged 5 months to 2 years and 3 months	Video recordings	Key elements of the teacher's pedagogical positioning were suggestive of the way through which the "ideal form" of concept formation can be introduced and supported in the infants' environment. 4 key elements for introducing science concepts in infants' everyday educational reality are proposed.
	Fridberg et al., 2019 [73]	Aimed to develop knowledge about the communication established between teacher and children in relation to an object of learning (inter-subjective communication).	Chemistry and physics concepts	Sweden, 5 children aged 3 to 5 years, 5 teachers	Video recordings	Intersubjectivity can occur in different ways with different consequences for children's opportunities to experience the intended object of learning.
	Havu-Nuutinen, 2005 [74]	Examined young children's conceptual change process in floating and sinking from a social constructivist perspective.	Floating/sinking	Finland, 10 children aged 6 years	Interviews (pre-post-test)	The child's awareness and interest were raised. Through challenging the child's thinking and encouraging the flow of ideas the foundations for later scientific understanding can be developed.
	Pramling and Pramling Samuelsson, 2001 [75]	Explore the verbal interaction between a child and teacher focusing on how the interaction enables the child to test and prove a self formulated hypothesis.	Floating/sinking	Sweden, 1 child aged 3.3 years	Video recordings	Conceptually orientated teacher–child interactions seemed to support the children's cognitive progress in cognitive skills and guided the children to consider the reasons for flotation.

* Studies examining science concept formation in the birth to three period.

3.2.1. Category 1. The Teaching of Science Concepts (Pedagogical Practices)

At the time of review, 25 of the 57 studies identified, examined science concept formation in the context of its relation to the teaching of science concepts (pedagogical practices); 24 related to children aged three to six years and 1 to children in the birth to three period.

The Teaching of Science Concepts (Pedagogical Practices): Three to Six Years

As earlier discussed, studies examining science concept formation in relation to pedagogical practices were further grouped into two sub-categories according to the more specific, research aim; studies exploring the effectiveness of specific teaching interventions/educational programs in relation to science concept formation (1A); studies exploring the effect of individual differences amongst teachers in relation to science concept formation (1B). Findings are now discussed in accordance with these sub-categories; 1A: Teaching Interventions/Programs; 1B: Individual Differences across Early Years Teachers.

1A. The Teaching of Science Concepts (Pedagogical Practices) (three to six years): Teaching Interventions/Programs

The majority of studies examining science concept formation in relation to pedagogical practices, explored the extent with which specific teaching methods and/or instructional strategies commonly used within the early childhood classroom/centre, facilitated children's learning of science. Teaching approaches examined included the combination of storytelling and drama [37], pictorial story reading [24], the use of electronic prompts built into touchscreen books [34] and the necessity of "physicality" (actual and active touch of concrete material) as a pre-requisite for science experimentation [38]. A cluster of studies have examined the relation between science concept formation and more broader teaching approaches including the use of responsive teaching and explicit instruction [23], narrative and paradigmatic modes of explanation [29] and inquiry based didactic methods [19]. The relation between teaching approaches differing theoretically, and science learning has also been explored including the effect of a socio-cognitive strategy on enhancing children in constructing a "precursor model" for the concept of friction [31] and light [33], Piagetian strategies [32], Cultural Historical Activity Theory [26] and a constructivist pedagogy [30]. Providing insight into the effects of different instructional strategies on science learning in early childhood specifically, the studies identified are pivotal in assisting early childhood teachers to develop appropriate strategies for teaching sciences [37].

Empirical research examining the efficacy of teaching interventions/educational programs is fundamental in providing a strong evidence base upon which emerging early childhood science practices and curricular reforms can be built [38]. A small group of studies identified in the current review examined the efficacy of specific teaching interventions/programs, in promoting scientific understanding, within the early childhood setting. Studies identified examined interventions in relation to the development of conceptual understandings of astronomical concepts [20,36], the construction of "pre-cursor" models to support scientific learning [25], the implementation of interventions designed to increase children's voluntary exploration of science centres during free choice play [28] and the combining of a museum and classroom intervention project on science learning in low-income children [35]. Positive outcomes in relation to the development of science concepts (in children aged 3–6 years) across all the identified studies was noted. That only 4 studies identified, examined the efficacy of specific teaching interventions is perhaps reflective of concerns within the wider literature, where a lack of outcome studies to support the implementation of innovative early childhood science curricular has been highlighted [76]. The provision of a strong evidence base is fundamental to the delivery of effective programs and best practice. The need for empirical work examining the efficacy of novel curricular and innovative classroom practices for science in early childhood is highlighted.

1B. The Teaching of Science Concepts (Pedagogical Practices) (three to six years): Individual Differences Across Early Years Teachers

A group of studies identified explored individual differences amongst teachers in relation to children's science learning experiences. Fleer [39] found individual teacher "philosophy" about how young children learn, to be a significant contributing factor to learning in science. Similarly, the level of individual teacher science "awareness" in relation to opportunities available in the environment, was found to be a contributing factor to science learning [42]. Domain specific self-efficacy has also been explored with an association found between teacher self-efficacy for science and the frequency of which children are engaged in science instruction [40].

Highlighting ways in which science opportunities provided in early childhood classrooms/centres can be enhanced (at the level of teacher education and the context of the everyday classroom) the studies on individual differences amongst teachers, have significant implications for teaching practices and child outcomes [40]. For instance, the association found between a lack of self-efficacy and time children are engaged in science instruction [40], supports the need for pre-service and in-service education programs to provide teachers with content and practices for science rather than focusing exclusively on literacy [40]. However, Fleer [39] draws caution to research in which a lack confidence and competence in teaching science is emphasised, suggesting that there is a tendency of such research to "blame the victim" whilst providing little analysis or insight into the reason. Instead, Fleer [39] argues that emphasis should be placed on individual teacher philosophy as this was found to have more of a difference to children's scientific learning than both teacher confidence in science teaching or science knowledge.

The Teaching of Science Concepts (Pedagogical Practices): Birth to Three

The literature review identified 1 study [27] in which science concept formation was examined in relation to pedagogical practices, in children aged birth to three years. This study is now discussed.

Research conducted by Lloyd et al. [27] represents the only study to empirically examine the teaching of science concepts (pedagogical practices) in relation to science concept formation of children in the birth to three period specifically. Seeking to bridge science learning across institutional practices of home and day care, Lloyd et al. [27] conducted an exploratory study of a "stay and play" service. A programme of activities aimed at encouraging parents' confidence in their own ability was delivered to support emergent scientific thinking. Findings demonstrated that the program generated children's engagement and interest and in addition, enhanced parental and practitioner confidence in their ability to promote young children's natural curiosity at home and in early childhood provision. The study found that parental interaction enhanced the children's learning at least as much, if not more than practitioner interventions. Based on this finding Lloyd et al. [27] highlight the significance of "familiar" adults in mediating young children's enjoyment and encouraging natural curiosity.

The significant role of an adult in mediating science learning experiences in infancy specifically, has been highlighted both in the context of the family home [66–68] and the educational setting [72]. As a key asset of a rich science learning environment in infancy [72], the significant role of an adult in mediating science learning experience in infancy specifically, illustrates a crucial difference in the science learning of infants in comparison to older pre-school age children. To Fragkiadaki et al. [72] (p. 19), "*the introduction of scientific concepts in the infant environment differs from a quick introduction or as something to be discovered without an adult guide*". That an assumption that teaching and learning practices used with older children can be used with infants is highlighted within the literature [77], underscores the imperative need for empirical research examining science learning in infancy period specifically.

3.2.2. Category 2: The Product of Science Concept Formation (Conceptual Understandings/Demonstrated Capabilities)

A substantial proportion of empirical research in science education (in general) has centred around identifying children's individual conceptual understandings at specific points in time. Most commonly, studies have used experimental clinical methods to elicit children's thinking in order to determine their specific conceptual understandings. At the time of review, 9 of the 57 studies identified, examined science concept formation in the context of its relation to conceptual understandings; all studies related to children aged three to six years.

The Product of Concept Formation (Conceptual Understandings/Demonstrated Capabilities): Three to Six Years

Exploration of children's conceptual understandings in relation to specific concepts identified in the current review included nature of science [43], ecological understandings [44], fossils [45], and electricity [50]. Studies have also examined children's conceptions and misconceptions [49] their ability to construct operational definitions in magnetism [46] and how and when scientific reasoning skills emerge in the early childhood [51,52]. Collectively this area of research provides us with a strong empirical insight into the conceptual understandings of children aged three to six years in relation to scientific phenomena. It is, however, important to note that reliance on these studies has been cautioned in relation to the (arguably) questionable validity of study methods; many approaches used to determine how children think about science concepts have been deemed suitable to use with young children without any questioning of their reliability when applied to this age group specifically [78]. The extent with which examining science concept formation in the early childhood is associated with methodological challenges are highlighted later in the paper.

The Product of Science Concept Formation (Conceptual Understandings/Demonstrated Capabilities): Birth to Three

No individual study examining conceptual understandings of scientific phenomena in children aged birth to three specifically was identified in the review. However, insight into a more cognitive perspective of science learning in infancy can be gained through discussion of the broader Cognitive literature. In contrast to the Piagetian view of infants as "irrational and pre-causal", a branch of cognitive research, conceptualises infants as "little scientists" or "theorists," actively attempting to build theories about the world [79]. Research centres around demonstrating the extent with which young children "think like scientists", testing hypothesis, making causal inferences and learning from informal experimentation [80]. In a 2011 review, Keil [81] concluded that young children share the cognitive "skills" of scientists, detecting correlations between seemingly unrelated phenomena, inferring causation, uncovering explanatory mechanisms and then sharing and building upon this knowledge with others. Similarly, in an overview of empirical studies in science in infancy, Gopnik [82] argues that infants learn about the world in the same way scientists do, analysing statistical data patterns, conducting experiments, and learning from the data and others. Using findings from an observational study Forman [47] argues that infants think like scientist because they use the same methods of, e.g., sensing the problem, and testing first. The small experiments, inventions, strategies, and pauses in young children's play captured in observations of toddlers' play illustrate a legitimate form of scientific thinking [47].

Painting an increasingly positive picture of young children as "active learners" [83] the (cognitive) research discussed, provides valuable insight into the cognitive processes associated with science learning in infancy. However, concerns with the cognitive premise on which the "little scientist" model is based have been highlighted. Nelson [84] (p. 6) argues that what the child brings to any conceptual domain is a built-in structure, fails to acknowledge outside influences on development; it is "*imperviousness to influences on basic cognitive processes or cognitive growth from outside the mind . . .* ". Consequently, the complexity of cognitive development, the significance of knowledge in the social and cultural world surrounding the child, are obscured [84].

3.2.3. Category 3: The Process of Science Concept Formation (Development over Time)

In contrast to research in which the primary focus has been to identify conceptual understandings, a number of studies identified examined *how* young children develop their understandings of science concepts; the "process" of science concept formation. At the time of review, 23 of the 57 studies identified, examined the process of science concept formation; 17 studies related to children aged three to six years and 6 to children in the birth to three period.

The Process of Science Concept Formation (Development over Time): Three to Six Years

Seeking to explore how young children form conceptual understandings in an everyday context, a number of studies have explored the collaborative nature of science learning [56–58,60,62,69,70] findings of which highlight the importance of collaborative experiences. Other studies have explored the dialectic interrelations between intellect, affect, and action during science experiences [61], the emotional nature of scientific learning [55] and the reciprocity between everyday thinking and scientific thinking during playful encounters [54]. The differing ways in which children represent natural phenomena have also been explored [53,59]. The way in which elements of the teachers' role, influence the *process* of concept formation, has been explored including sustained and shared conversations between children and teachers [71], intersubjective communication (intersubjectivity) [73], contextual and conceptual intersubjectivity [64], conceptually orientated teacher–child interactions [74] and verbal interaction between a child and teacher [75].

Examining the process of science concept formation, studies in this category have primarily been conducted within a Socio-Cultural (SC)/Cultural-Historical (CH) theoretical framework. Focusing on the contexts in which children develop socio-culturally relevant activities, and the interactions with others that support and guide them [85], SC/CH research is suggested to provide a powerful and authentic approach to researching young children's thinking [6]. That as suggested by Robbins [85], individual thinking does not occur in a "vacuum" separate from activities in which people engage, highlights the value of this group of studies in relation to our understanding of science concept formation in the early years.

The Process of Science Concept Formation (Development over Time): Birth to Three

Representing the largest area of research examining science concept formation in the infancy period specifically, six of the seven studies identified in the review explored "how" children (as infants) are forming science concepts; the process of concept formation. Adopting a Cultural- Historical approach, Sikder and Fleer [66–68], examined infant-toddler's development of science concept formation within the family context. Based on Vygotsky's theory of concept formation, Sikder and Fleer [67] identified and categorised what they termed "small science", the toddlers' engagement and narration accompanying the small moments of their "everyday activities". They propose that "small science" can help explain how the everyday experiences of young children lay the foundation for the development of concrete "scientific" concepts. In a later paper, Sikder and Fleer [68] examined how these small science concepts become "ideal forms" from "real forms" in everyday life during the infant–toddler age period; findings indicated a conscious collaboration between parents and infants was key for developing small science concepts from rudimentary to mature form.

Providing a similarly cultural-historical examination of science concept formation, a large programmatic study (Fleers Conceptual PlayLab (CPL) in Melbourne, Australia) examined science concept formation in infancy in the context of an educational setting [72]. Using a model of intentional teaching called a Conceptual PlayWorld (CPW) [56], as an Educational Experiment, Fragkiadaki et al. [72], examined how infants in play-based settings, develop scientific understandings about their everyday world. Using visual methods and concepts from Cultural Historical Theory (CHT), 4 key elements for introducing science concepts in infants' everyday educational reality were identified: (a) making dialectic interrelations between the everyday concept and the science concept, (b) consistently using a science language, (c) using appropriate analogies, and (d) using early forms of a scientific method.

Conducted within a similar cultural-historical framework Larsson [65], explored preschool children's opportunities for learning about friction focusing on four children and their everyday experiences within a Swedish preschool setting. Using the visual method of "shadowing" (direct observation using a video camera with a focus on a particular person), Larsson [65] found that during everyday situations and during play, a range of activities occur that place children in contact with the phenomenon of friction (e.g., when they shuffle, slide, or push). Children encounter the phenomenon of friction in many everyday situations, without reacting or reflecting upon it [65]. Larsson [65] suggests that such findings highlight the extent with which everyday play situations can be used by teachers to become more knowledgeable about children's current understandings of the phenomenon and ways of directing their attention toward understanding of friction in a more explicit manner, such as by inspiring children to new forms of play where the phenomenon of friction is prominent.

In similarity to Larsson [65], Klaa and Ohman [63] examined how children, as infants, encounter the phenomena of friction. Focusing on the way in which infants form science concepts through their actions in nature, Klaa and Ohman [63] provide insight into how the process of "meaning making" can be examined in infancy in the context of science. According to Klaa and Ohman [63], the investigation of meaning making should not be restricted to science concepts; analysis must relate to encounters with nature as one aspect among several in young children's lives. Accordingly, Klaa and Ohman [63] present and illustrate an approach that allows for the analysis of toddlers' meaning making when they physically encounter and experience nature in everyday practice. Based on Dewey's philosophy of Pragmatism, Klaa and Ohman [63] argue that their 'pragmatic action-oriented' perspective of learning can facilitate the analysis of toddlers' meaning making processes in early childhood education settings, contributing to a deeper understanding of the basic foundation for children's meaning making of nature.

Overall, there exists a plethora of methodological challenges associated with research involving children in the infancy period. The studies discussed provide valuable insight into ways in which the complexity of young children's science learning has and can be captured. The use of visual methodologies and Practical Epistemological Analysis, to gain insight into the child's everyday context were highlighted in the review and offer promising avenues for future exploration. In addition, this group of studies highlight the extent with which research into science concept formation in infancy specifically, has centred around examining the "process" of concept formation from a predominantly socio-cultural/cultural historical perspective. In contrast, the literature on older preschool age children has tended to adopt a constructivist approach which traditionally, has examined a child's demonstrated understanding of a particular science concept at a particular point in time; the "product" of concept formation. This difference is perhaps reflective of methodological challenges inherent in research with very young children.

4. Conclusions

Within the context of early childhood science education, we have a strong, empirically based understanding of science experiences for children aged three to six years. In contrast, our understanding of science learning as it occurs for children from birth to three, is extremely limited. We know very little about how and in what way children as infants and toddlers form conceptual understandings in science. Seeking to gain insight into current empirical understandings of science concept formation in the infancy–toddlerhood period, a review of the literature on early childhood science education (birth to six years) was conducted. The literature review focused specifically (and for the first time) on children in the birth to three period.

Findings of the review illustrate a clear gap in the literature regarding science concept formation in the birth to three period; very little is known about infant and toddlers' thinking in science when considered in the context of birth to six years. Infants can and do engage in science [7] and the assumption that a particular developmental level must be reached before children can be taught science concepts has been challenged [72]. However, only a handful of empirical papers have examined science concept formation in the infancy–toddlerhood period specifically; we do not know enough about how science and scientific thinking can and does begin from birth [72]. The eminent need for empirical research to address this gap is highlighted by this review.

The lack of empirical research examining science concept formation in the birth to three period, identified in this review, can in part, be attributed to the methodological challenges inherent in research involving very young children. Determining how for example, the thinking of an infant with limited verbal skills can be documented, presents the researcher with a profound challenge. The fact that historically, infancy has been viewed as a period of helplessness may also explain the lack of empirical research identified; infants traditionally, have not been conceptualized as active, capable, "scientists". That infancy is a period in which there is no formal schooling, further complicates the construction of an empirical basis.

5. Science Concept Formation in the Birth to Three Period: Key Points from the Literature

In completing the review, a number of key points regarding the empirical literature on science concept formation in infancy and toddlerhood, were identified.

1. Studies examining science concept formation in the birth to three period specifically, have focused primarily on exploring the process of concept formation; 6 of the 7 studies identified examined how young children develop their understandings of science concepts in an everyday context. This is in contrast to the literature on older pre-school age children (three to six years), where the tendency of research has been to focus on the relation between science concept formation and pedagogical practices; 24 of 50 studies (examining science concept formation in children aged three to six years) examined the relationships between teaching practices and children's conceptual development.
2. Studies examining science concept formation in birth to three period, have tended to draw upon socio-cultural/cultural historical theory; 5 of the 7 studies identified, adopted a SC/CH theoretical framework. From a SC/CH perspective, cognitive development is conceptualised as a process whereby people move "through" understanding as opposed to towards it [86]. Concept formation is therefore, conceptualised as a dynamic process that must be examined as it occurs within and across differing contexts [54]. Research examining science learning in the birth to three period specifically, has focused on the "process" of concept formation. Within the broader Early Years Science Education Research (EYSER) literature, the tendency of research, to adopt a constructivist approach has been highlighted [6]. In contrast to SC/CH research, research adopting a constructivist approach has historically, examined children's demonstrated understandings of a particular science concept at a particular point in time. Thus, in contrast to the literature on science concept formation in infancy–toddlerhood, the literature within EYSER in general, has tended to examine the "product" of concept formation.

The greater emphasis placed on the process (as opposed product) of concept formation, seen in the literature on science in the infancy period, is, perhaps reflective of the difficulties inherent in using clinical methods to ascertain conceptual understandings of infants and toddlers (seen in broader constructivist approaches). Traditionally, EYSER research adopting a constructivist approach, has examined children's mental representations and understanding of science phenomena [61], findings are therefore based on children's elicited responses, expressions of their thinking. Such methods, however, rely heavily on a certain level of cognitive awareness/verbal skills. The inherent challenges this presents when research involves very young children is highlighted.

In summary, the overall findings of the review provide clear evidence that a gap exists in the literature regarding infant and toddlers' thinking in science, very little is known when considered in the context of birth to six years. Urgent research attention is needed to take forward and to provide education systems with more evidence of infant and toddler thinking in science and what kinds of pedagogical approaches can amplify science thinking in the first period of children's lives. Without research within this early period, we do not have a sense of the continuum of science learning, under what conditions, what kind of methods are needed to study this period, or indeed how teachers can plan for infant-toddler development of science concept formation. This review paper gives the possibility to take stock of the gaps, and to point to new directions in science education research.

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Children's Astronomy. Development of the Shape of the Earth Concept in Polish Children between 5 and 10 Years of Age

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Abstract: The Earth's shape concept develops as consecutive cognitive problems (e.g., the location of people and trees on the spherical Earth) are gradually resolved. Establishing the order of problem solving may be important for the organisation of teaching situations. This study attempted to determine the sequence of problems to be resolved based on tasks included in the EARTH2 test. The study covered a group of 444 children between 5 and 10 years of age. It captured the order in which children solve cognitive problems on the way to constructing a science-like concept. The test results were compared with previous studies. The importance of cultural influences connected to significant differences (24%) in test results was emphasised. Attention was drawn to the problem of the consistency of the mental model approach highlighted in the literature. The analysis of the individual sets of answers provided a high level of consistency of indications referring to the same model (36%), emphasising the importance of the concept of mental models.

Keywords: shape of the Earth; conceptual development; mental models; astronomy; EARTH2 test; knowledge-as-elements; knowledge-as-theory; cultural differences

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1. Introduction

The development of concepts about the shape of the Earth and its place in space in children consists in gradual departure from personal experience [1–3]. First, based on everyday experience, children construct the concept of a flat Earth, and then, as a result of collecting information transmitted culturally, they build more science-like concepts [4–7]. Although research into this process has been ongoing for several decades now [1,7–11], it seems that the issue of conceptual development with regard to the shape of the Earth is still not exhausted. Reasons for the current state of affairs are theoretical doubts about how children construct their knowledge and recently raised methodological issues related to criticism of the concept of mental models [12,13].

Proponents of the knowledge-as-theory concept [14–16] based on the legacy of Jean Piaget [17] came to the conclusion that children construct explanations that resemble scientific theories in terms of function and structure. Their conclusions were based on studies dominated by methods that use open questions [1,18]. When encouraged to make entire statements, children seem to present a logical explanation of astronomical objects and phenomena [7]. Vosniadou and Brewer [1] refer to these coherent explanations of the Earth's shape as mental models.

Personal experience is considered to be the foundation for creating mental models. Based on them, children construct concepts [15], which for reasons of consistency Vosniadou refers to as initial models. As children come into contact with adult explanations, they gradually begin to include them in their explanations, thus creating synthetic models. It is believed that changes in beliefs (restructurings) do not occur globally (as described by Piaget [19]), but rather within a certain domain, i.e., are domain specific [15]. Additionally, these restructurings do not happen smoothly, as a kind of resistance is observed [20]. In addition, such a change in beliefs does not involve elimination, but rather overwriting [15,21]. The transition from intuitions to scientific concepts is gradual, and the correctness of the beliefs constructed along the way (synthetic models) depends on many variables: (a) the amount of information available, in particular its quality and accuracy, (b) access to scientific knowledge and the level of competition from common sense knowledge, (c) the number of situations where children have the opportunity to reflect on the sphericity of the Earth and their mental capabilities [1,4,6,11,22–26].

Mental models of the Earth's shape by Vosniadou and Brewer have been confirmed in Western countries [11,27], and also recently in Poland [28]. However, due to some observed cultural differences, it seems important to verify the models before taking them into account. The method used in Polish studies was an interview, supported by practical activity—children built plasticine models of the Earth's shape and pushed minifigures into it to locate people on the planet. Based on the children's statements, three shapes of the Earth were identified: a sphere, a flat disc and a strongly flattened cuboid. In terms of location, five different concepts have been identified:

- People live on the surface of the Earth, which is a flat cuboid (two children),
- People live on the upper surface of the Earth, depicted as a flat disc (11 children),
- People live on the upper and lower surface of the Earth, depicted as a flat disc (one child),
- People only live at the top of the spherical Earth (nine children),
- People live on all sides of the spherical Earth (26 children).

The mental rules that guide children when explaining the shape of the Earth (support and flatness) and cosmological relations (relative locations and motions of objects) were also confirmed. In the process of conceptual development, these rules constitute an important element of shaping the concept of the Earth's sphericity and the day and night phenomenon.

The idea of mental models assumes that children constantly have a certain amount of information at their disposal, from which they form coherent concepts. Meanwhile, other researchers point out that children do not have a ready explanation at hand at all times, but create answers on the spur of the moment based on their experiences—superficial interpretations of reality (p-prims [2]). Recent studies seem to provide evidence for the concept of knowledge-as-elements [3,12,13]. It is believed that when experiencing objects and phenomena, children store experiences and bits of information heard from adults (*fragmentation* [12]). On that basis, they formulate concepts which, however, are not internally as organised as theories. It is the degree of coherence and organisation that is the greatest difference between the concept of knowledge-as-theory and knowledge-as-elements [17].

Vosniadou [21], while acknowledging the findings of the fragmentarists, stated that there is a part of children's explanations which does not change (she calls it a "framework"). She stated that permanent elements of the concept remain the same, while elements of this structure change. Vosniadou considered the shape of the Earth to be the framework, and the changeable elements include, among other things, the location of people and clouds. To verify the existence of models, proponents of the fragmentation theory used Vosniadou and Brewer's [1,29] mental models of the Earth's shape as a basis for a forced-choice test [13]. The authors of the test assumed that if the respondents adhered to one and the same representation of the Earth's shape in their answers, then one could indeed speak of stable mental models. The authors interpreted the results obtained as low consistency of children's indications and stressed the importance of the knowledge-as-elements concept.

It is in such a climate of debate that the EARTH2 test was created. The test consists of nine questions and a set of answers presented in the form of pictures which graphically correspond to mental models of Vosniadou and Brewer. It was assumed that the methods used to date, with open questions and analysis of children's creations (drawings and clay structures), are difficult to interpret [24,30]. It was assumed that the most reliable research tool would be a forced-choice test [13]. It was emphasised that this type of tool would make it possible to diagnose children's representations of the Earth's shape in an economic way. Furthermore, the fact that such tools tend to generate more indications of scientific answers was considered to be an added value [10,24,30]. However, opponents of the use of forced-choice tests point to its shortcomings. They stress that limiting the choice to five or six answers does not capture the reasoning of children [21]. It was pointed out that mental models depend on the influence of culture [22,23]. The use of forced-choice methods does not capture new concepts. In addition, the test also fails to identify the argumentation of children if the respondents should disagree with any of the answers. According to the authors of the test, if the questions are well designed, then children will have no doubt as to the choice of answers [13]. In order to verify the diagnostic utility of the test, a comparison was made between the test results and the interview, where statistical convergence was found.

However, on consideration, the test method used is problematic. First of all, solving cognitive problems by drawing and modelling, as well as just thinking about answering, can change beliefs [30]. The children who had previously completed the test with ready-made pictures and then participated in the interview first had the opportunity to reflect on the questions (e.g., where people live on Earth, how they move), and then, after a suggestion of sorts, answered the same questions during the interview. When the children responded, they remembered the picture from the test and talked about it during the interview. Since the results were very convergent, it can be assumed that this was the case. What happened here was that the period between solving the test and participating in the interview was too short. Since the authors of EARTH2, do not specify a reminiscence period, it should be assumed that the high convergence in the test and interview results comes from the short period between the completion of the test and the children's participation in the interview. Perhaps the convergence would have been different if the children had been asked to provide full answers first and then had taken the test. This is evidenced by the fact that more correct answers were provided in forced-choice tests than for open-ended questions [10,21].

Secondly, the interview involved a forced choice. The children were asked a series of nine questions (similar to those included in the EARTH2 test). The interview started by choosing one of a number of polystyrene foam models. Then, on the basis of the chosen model, the children were to answer questions about the location of people, trees, the way people move on Earth and so on. The choice of the polystyrene shape imposed a limitation on the possibility to study children's reasoning. During the test, the child was no longer able to change his/her choice to another model of the Earth's shape, although probably many would have wanted to, given that the test showed a low consistency of choices of a single model [13]. Changes in the choice of the Earth's shape were also reported in subsequent studies [31].

To date, the EARTH2 test has been used for two purposes: (a) to measure the increase in knowledge in experimental research and (b) to verify the theory of mental models. As a screening tool, the test was used by Yildiz, Güçhan Özgül and Saçkes [32]. It was instrumental in determining the educational impact of activities for children in experimental research. The study was conducted among 44 children aged 5–7 years in order to determine how they understand the day and night cycle and the shape of the Earth.

To test the concept of mental models, the EARTH2 test was used in studies conducted among Dutch [13] and Greek [31] children. The study was conducted on large groups of children, N = 379 and N = 184, aged 4 to 9 years and 6 to 8 years, respectively. The latent class analysis (LCA) revealed that children do not adhere to a single shape of the Earth, which was considered to contradict the consistency of mental models. The study did not reflect on the relationship between children's indications to individual questions in the test. It was limited to a general analysis of all responses as indicators of mental models. However, the analysis of individual choices—as described in this article—allowed us to draw deductions about the children's reasoning and determine the level of consistency, while relations between answers of different age groups provided information on conceptual development with regard to the shape of the Earth and the phenomenon of nightfall.

If one wants to understand children's reasoning, one should examine the manner in which the EARTH2 test is carried out. The initial instructions do not reveal that children would answer questions about the shape of the Earth and related problems. Thus, the child recognises the context of the study as he or she learns the consecutive test questions. It is presumed that when the child hears the first question (What does the Earth look like?), he or she will realise the context of the whole study, e.g., the perspective of looking at the Earth in each subsequent question. When reading the consecutive questions, the researcher expects the child to guess the context and provide answers, whereas the atmosphere of silence and individual work during the test make it impossible for a child unable to understand the context to ask the researcher any questions. If the child grasps the context too late, then, even if they realise that the answer they gave to the previous question was wrong, he or she is no longer able to correct it, as the researcher is already reading the next question and expects the child to mark only one answer per question. So, a research situation with the use of a forced-choice test not only narrows down how one's own beliefs are formulated (they have to match one of the pictures/answers), but also limits the possibility to self-correct. Until now, this perspective seems to have escaped the researchers using this test because they focused on the analysis of children's responses as a whole.

The research methodology adopted to date does not raise any statistical concerns, but the interpretative direction does create a puzzle. There are several reasons for this: (a) the reliance on ready-made mental models seems to disregard cultural influences. Meanwhile, the development of children's astronomical concepts depends on access to scientific knowledge and the competing common sense knowledge [22,23]. (b) The argument about the importance of in-depth statistical analysis seems to marginalise the importance of qualitative research. In turn, the fact that statistical research is based on well-described mental models of the shape of the Earth in itself proves the importance of qualitative research. After all, the method of questioning supported by action (creating plasticine models and drawings) allows us to penetrate the child's way of thinking and describe their mental representation of the surrounding world [1,29]. (c) The decision not to analyse individual answers (indications) to the test questions proves that the research carried out served the purpose of a general understanding of children's reasoning without penetrating the problem of conceptual development with regard to the shape of the Earth. However, because we are still unable to fully describe the process of constructing basic astronomical concepts, e.g., the shape of the Earth [31], the failure to analyse individual questions narrows down an interesting research field.

This article presents an analysis of individual indications between questions, e.g., concerning the location and movement of people on Earth (questions 2 and 7 of EARTH2) and concerning the location of people, clouds and trees on Earth (questions 2, 3 and 5). In addition, the results were interpreted in relation to research that was previously carried out on another group of children by means of an interview with open questions and building a plasticine Earth, Moon and Sun as well as pushing minifigures into them to mark the location of people on Earth [28]. The results obtained in studies using the EARTH2 test will be supplemented by the conclusions of the studies conducted using an interview. The data collected on the basis of qualitative (interview) and quantitative (test) research will not be compared with each other, but will be supplemented with interpretations, in order to broaden the knowledge about the process of conceptual development with regard to the Earth's shape in children.

The study sought to answer the following questions: (1) where children between 5 and 10 years of age locate people and trees on the Earth as well as clouds in the sky, how they explain the movement of people and a ball on the Earth and the nightfall phenomenon; (2) how children's concepts change between the ages of 5 and 10; (3) how consistent are children's concepts when comparing children's answers to the individual questions in the EARTH2 test (but not all answers). It also sought to determine cultural differences based on a comparison of EARTH2 test results.

For the purposes of this article, the term mental models will only be applied in relation to the answers/images included in the EARTH2 test. In other places, the term concept will be used or, in the context of development: *intuitions*, *outlines of concepts* and *science-like concepts*. The term *intuitions* is understood as the essence of everyday experience (intuitions correspond to initial models), *outlines of concepts* are understood as mental constructs which emerge as personal experience clashes against information received from adults (they correspond to synthetic models), while *science-like concepts* appear as outlines of concepts are refined and scientific knowledge is absorbed (they correspond with scientific models). The use of these terms (a) follows the course of human development (characteristic of mental models), (b) refers to the tradition of concepts as mental building materials [19,33], (c) bearing in mind the (presently) debatable consistency of mental models adopted in the definition of Vosniadou [1,21], allows us to safely describe the nature of constructing representations.

2. Materials and Methods

This study used the EARTH2 test, translated into Polish. It had been chosen because: (a) it is designed to establish children's representations of the shape of the Earth quickly. (b) The test questions contain a scientifically interesting set of cognitive problems that children have to solve on the way to constructing a science-like concept. (c) The research carried out among Polish children [28] did not reveal any mental models other than those described by Vosniadou and Brewer [1,29], based on which the test has been developed. The lack of differences has eliminated concerns about cultural differences.

The EARTH2 test contains nine questions, which are presented to children in the form of a 10-page booklet. Each question contains a set of five or six answers presented as pictures. It is assumed that by choosing a picture (graphic representation), the child indicates to the researcher a mental model corresponding to his/hers. The test involved handing out booklets to the children, having the researcher read out a series of questions and waiting for the children to choose one of the given answers/pictures.

Four hundred and forty-four children aged five to ten years (M = 7.6) participated in the study procedure. Among them, 99 children were five and six years old, 242 children were seven and eight years old and 103 children were nine and ten years old. In this group, there were 252 boys and 192 girls; 206 children came from a city (40,000 inhabitants) and the remaining 238 children from a village 10 km away.

3. Results

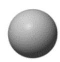
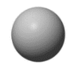
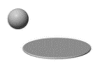
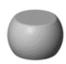
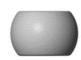
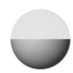
In the EARTH2 test, children were given ready-made answers/pictures and asked to select the one they considered the most appropriate. The children's detailed answers to all the test questions are presented in Table A1 (Appendix A). This table also includes results from studies among Dutch and Greek children, which will be summarised later in the article.

3.1. Shape of the Earth

To the first question: *What does the Earth look like?* the vast majority of children (98.6%) responded that it was spherical in shape. Only a small percentage (1.4%) marked a different shape of the Earth. It is surprising that all 5-year-olds, while selecting graphic representations, chose the one which emphasised the spherical character of the Earth. Similar results (96.6%) were obtained in the control question (8) *Which picture resembles the Earth best?* I would like to add that in a study carried out using a lump of plasticine, only 71.4% (35 out of 49 respondents) thought that the Earth was spherical.

Table 1 summarises the answers to both questions. The first column contains schematic images of the shape of the Earth from the EARTH2 test, ordered from the scientific model to the initial model. Presenting the answers to question 8, we give the number of children who marked pictures corresponding to the same model (i.e., the scientific model) in both questions. This summary shows the extent to which the children surveyed adhered to the pre-selected answers (consistency).

Table 1. Consistency of answers regarding the questions What does the Earth look like? (1) and Which picture resembles the Earth best? (8).

Question 1	Number of Indications	Question 8	Number of Indications [1]	Age		
				5–6	7–8	9–10
	438 98.6%		426 95.9%	94.9%	95.5%	98.1%
	4 0.9%		2 0.5%		0.4%	1%
	1 0.2%					
						
	1 0.2%		1 0.2%		0.4%	

[1] The percentages do not add up to 100% as they only represent the share of children who indicated the same shape of the Earth in questions 1 and 8.

It is important to mention that when solving the EARTH2 test, children in each age group pointed out that the question about the shape of the Earth had been asked before, which shows that they were aware of the nature of previous answers. This is important as the order in which the questions were asked influenced the answers. When asked questions 1 and 8, children who chose different graphic representations (pictures) either could not remember the questions or were unsure about the shape of the Earth.

The number of indications of the spherical shape of the Earth changed as children answered the subsequent questions. When they answered a question about the location and movement of people and objects, they would gradually abandon indications of spherical Earth pictures. The details are presented in Table 2. In the test, e.g., in question 2: *Which picture shows best where the people live on the Earth?* the spherical Earth was represented by two pictures: (a) people live on all sides of the Earth (scientific model) and (b) people live only at the top of the Earth (synthetic model), and the following table includes indications for both answers/pictures.

There were 30% of children who consistently indicated the Earth as a sphere in all test questions (*Choose the picture which best...*). The number of indications in each age group increased from 15% in five- and six-year-olds to 49% in nine- and ten-year-olds. These children had already abandoned intuitions (the Earth is flat) in favour of outlines of concepts (the Earth is spherical). It turned out that the older a child is, the more certain he or she is that the Earth is spherical.

Interestingly, when in the analysis answers to questions 1 and 8, i.e., direct questions about the shape of the Earth, were skipped, 5.9% of all children chose pictures depicting a flat Earth. In questions 1 and 8, these children, presumably wanting to meet the adult's expectations, chose a picture depicting a spherical Earth and/or a spherical Earth image is familiar to them (books, TV).

Table 2. Share of indications of pictures depicting a spherical Earth.

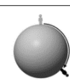
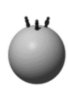
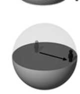
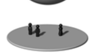
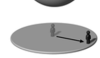
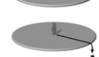
Question (Number of Answers Presenting the Spherical Image of the Earth).	Percentage of Indications	Age		
		5–6	7–8	9–10
1. *What does the Earth look like?* (hollow, scientific)	98.6%	100%	97.9%	99.0%
2. *Which picture shows best where the people live on the Earth?* (hollow, scientific)	83.8%	79.8%	83.1%	89.3%
3. *Which picture shows best where the clouds are?* (hollow, scientific)	81.1%	76.8%	79.8%	88.3%
4. *Which picture shows best what happens when a giant kicks a ball real hard?* (hollow, scientific)	68.2%	63.6%	68.2%	72.8%
5. *Which picture shows best where the trees are on the Earth?* (hollow, scientific)	62.2%	53.5%	62.4%	69.9%
6. *Where is the Sun at night?* (hollow, no gravity, scientific)	46.4%	27.3%	46.7%	64.1%
7. *What happens when you walk along a straight line for a very long time?* (hollow, scientific)	45.0%	27.3%	45.4%	62.1%
8. *Which picture resembles the Earth best?* (dual Earth, hollow, scientific)	44.1%	27.3%	43.4%	62.1%
9. *Which picture shows best how night falls?* (hollow, scientific)	30.2%	15.2%	28.1%	49.5%

3.2. Location and Movement of People on Earth

In the EARTH2 test, children answered the question: (2) *Which picture shows best where the people live on the Earth?* A surprisingly large number of children (62.6%) chose the picture that depicted people positioned around the planet (Table A1 in Appendix A). In a study in which, after forming the shape of the Earth out of plasticine, children pushed Lego minifigures into it, only 53.1% (26 out of 49 children) placed people around the spherical Earth and were able to justify it verbally.

However, comparing question (2) Which picture shows best where the people live on the Earth? and question (7) What happens when you walk along a straight line for a very long time? (Table 3), it turned out that more than 13% of the children abandoned the scientific answer.

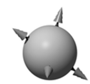
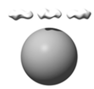
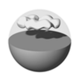
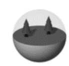
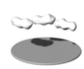
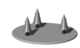
Table 3. Where people live and how they move on Earth.

Question 2	Number of Indications	Question 7	Number of Indications [1]	Age		
				5–6	7–8	9–10
	278 62.6%		218 49.1%	28.3%	49.6%	68%
	99 22.3%		15 3.4%	8.1%	2.9%	
	5 1%		0			
	26 5.9%		9 2%	1%	2.9%	1%
	36 8%		7 1.6%	2%	1.7%	1%
			3 0.7%	2%	0.4%	

[1] The percentages do not add up to 100% as they only represent the share of children who indicated the same shape of the Earth in questions 2 and 7.

Locating humans on Earth requires that, in their reasoning, children combine: (a) a belief in the sphericity of the Earth (for many children, the idea of a flat Earth is closer due to direct experience) and (b) an elementary understanding of how gravity works. It can include intuitions (objects can also fall from spherical objects) and outlines of concepts (there is something at the centre of the Earth that attracts objects and therefore they do not fall off). The data in Table 4 show that the number of children who are consistently guided by the belief that the Earth is spherical increases with age. This includes an intuitive understanding of the phenomenon of Earth's magnetism, which implies that people can move around the Earth's surface without fear of falling off the Earth and floating into space.

Table 4. Consistency of answers to questions about the location of people, trees and clouds.

Question 2	Number of Indications	Question 3	Number of Indications [1]	Question 5	Number of Indications [2]
	278 62.6%		207 46.6%		157 35.4%
	99 22.3%		51 11.5%		35 7.9%
	5 1.1%		5 1.1%		1 0.2%
	26 5.9%		6 1.4%		5 1.1%
	36 8%		10 2.3%		10

[1] The percentages do not add up to 100% as they only represent the share of children who indicated the same shape of the Earth in questions 2 and 3. [2] The percentages do not add up to 100% as they only represent the share of children who indicated the same shape of the Earth in questions 2, 3 and 5.

It is interesting that out of 99 children who, in question 2, stated that humans only lived at the top of the planet, as many as 63 also claimed that it was possible to go around the spherical Earth and it was impossible to fall down (they chose the scientific model). This type of inconsistency is related to solving the problem of Earth's gravity and its influence on human life. These children probably tried to recall any available information about cases of man falling off the Earth, and since they found none, they decided that it was impossible.

The analysis of indications of 62 children (14% of respondents) who selected a flat model of the Earth in the test has shown that only 4% were consistent in choosing this shape of the Earth throughout the study.

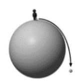
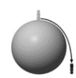
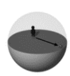
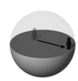
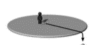
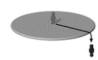
3.3. Location of People, Trees and Clouds

In the EARTH2 test, children answered the questions: Which picture shows best where the people live on the Earth? (question 2), Which picture shows best where the clouds are? (question 3) and Which picture shows best where the trees are on the Earth? (question 5). The numbers of indications for each of these questions separately can be found in Table A1 (Appendix A). In terms of content, the issues addressed by these questions are related. Clouds float in space at a certain height and can be interpreted differently from the location of people or trees on the Earth. However, by comparing the answers to these questions, it is possible to establish what guides children in interpreting the location of these objects.

Table 4 presents the number of children who showed consistency when choosing answers/pictures to the questions listed. The first column shows the graphic representations of the location of people on the Earth related to question 2 of the EARTH2 test, together with the number of indications to each answer. The following columns show the answers and the number of children who adhered to the same choice throughout the test.

The data in Table 5 show that more than one third (35.4%) of all children surveyed (aged 5 to 10) are so sure that the Earth is spherical that they can draw inferences about the location of people and trees on the Earth and clouds in the sky. These children chose pictures that show that people and trees are located around the spherical Earth, and clouds in the sky are visible from anywhere on Earth. This astronomical knowledge was represented by both 5- and 6-year-olds (16%), 7- and 8-year-olds (33.1%) and 9- and 10-year-olds (59.2%).

Table 5. Where people live and how they move on Earth.

Question 4	Number of Indications	Question 7	Number of Indications [1]	Age		
				5–6	7–8	9–10
	224 50.5%		204 45.9%	31.3%	47.1%	57.3%
	122 27.5%		34 7.7%	13%	7.9%	1.9%
	16 3.6%		1 0.2%	1%		
	34 7.7%		16 3.6%	2%	4.5%	2.9%
	35 7.9%		11 2.5%	2%	2.9%	1.9%
	13 2.9%		1 0.2%		0.4%	

[1] The percentages do not add up to 100% as they only represent the share of children who indicated the same shape of the Earth in questions 4 and 7.

In the next two rows of the table, data are given for the children who, for the three questions listed above, chose pictures depicting the Earth as a sphere or a slightly flattened ball. However, they only located people and trees on the upper or on the upper and lower surface of the flattened Earth. They located clouds in the sky, which enveloped the Earth only in specific places—at the top or at the bottom and the top of the Earth. This was the case for 8% of the children, i.e., 36 respondents.

The last two rows contain data on 15 children (just over 3% of all respondents) who, in the EARTH2 test, chose images of a flat Earth with people and trees located on a flat surface, and clouds located in the sky visible from the flat Earth.

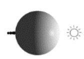
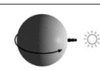
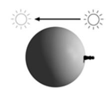
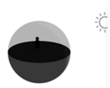
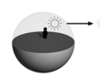
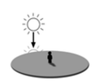
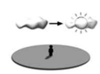
3.4. Movement of a Ball and People on Earth

In the EARTH2 test, there are two separate questions about the movement of people and a kicked ball on the surface of the Earth. After hearing each question, children were asked to choose one of several pictures which they thought was correct. The data for these responses are given in Table 5. The first column contains answers to question (4) *Which picture shows best what happens when a giant kicks a ball real hard?* and the second one, answers to question (7) *What happens when you walk along a straight line for a very long time?*

Answering questions about movements on the Earth's surface requires children to have some awareness of gravity. In Polish schools, the phenomenon of gravity is not discussed until the fourth grade, so the children surveyed did not have the opportunity to learn about it at school. It is also difficult to expect parents (in out-of-school education) to explain the consequences of this phenomenon to the child. Nor is the phenomenon of gravity introduced to children in the available publications on natural phenomena.

Nevertheless, the data in the first row of Table 6 show that almost half of the respondents (45.9%) consistently state that people and objects (a ball) will move across the entire surface of the spherical Earth. These children use science-like concepts when considering the movement of objects on the surface of the Earth. The other children surveyed did not share that opinion, as evidenced by the data in other rows of the table. Therefore:

Table 6. Consistency of answers to the question about the location of the Sun at night as well as nightfall.

Question 6	Number of Indications	Question 9	Number of Indications [1]	Age		
				5–6	7–8	9–10
	241 54.3%		69 15.5%	4%	15.3%	27.2%
	46 10.4%		18 4.1%	3%	4.5%	3.9%
	33 7.4%		5 1.1%	2%	1.2%	
	87 19.6%		56 12.6%	21.2%	12.8%	3.9%
	37 8.9%		15 3.4%	6%	3.7%	

[1] The percentages do not add up to 100% as they only represent the share of children who indicated the same shape of the Earth in questions 6 and 9.

- the second and third rows contain data on the number of children who believed that the Earth was round or sphere-like in shape, but at the same time believed that it was possible to fall off the Earth. These children (35) showed constant beliefs in relation to the movement of a ball and people on the surface, however, when marking pictures they were convinced that the Earth had a boundary from which one could fall.
- the fourth, fifth and sixth rows contain data on the number of children who believed that the Earth was flat and that both humans and balls move only on its upper part. The same applies to the views of children who believe that if people and balls do not stop at the edge of the disk, they might fall off it.

The greatest inconsistency in the application of beliefs about the movement of a ball and people on Earth was observed in the synthetic models. Over 27% of the children believed that a ball could fall off the Earth, but only 7.7% of the children believed that the same could happen to humans. Seventy children thought that while a ball could fall off the Earth, a human being would not. The difference, possibly, may relate to the fact that the ball is inanimate or still, as opposed to a human being. Probably, if the order of questions had been different (e.g., the question about the way people move first, and then the one about the ball second), the results would have been different.

3.5. The Phenomenon of Day and Night

What children think about the phenomena of day and night can be established by comparing answers to the questions *Where is the Sun at night?* (6) and *Which picture shows best how night falls?* (9). Data on the consistency of picture choices can be found in Table 6.

In explaining the phenomenon of nightfall, children show the greatest inconsistency. In all previous statements, the inconsistencies applied to synthetic models; here, the problem applies to the scientific model. Only 15.5% of respondents consistently used the scientific model in questions about the night. The indications of the majority of the remaining children, broadly speaking, were divided between two answers/pictures. Of all respondents, 18.9% (84 children) indicated a picture in which the Sun moves along the top edge, and 16.4% (73) of the children indicated a picture in which the Sun sets over the horizon.

The data in Table 7 show that about 4% of the respondents were convinced that the Earth is a sphere, but did not associate the brightness of the day with sunlight. The data in the third, fourth and fifth row indicate that about 17% of the children chose pictures showing different variants of a flat Earth with the Sun located above the surface of such an Earth.

Table 7. Percentage of picture choices by age group.

Question	Model	Age		
		5–6	7–8	9–10
1. *What does the Earth look like?*	Initial	0.0	0.4	0.0
	Synthetic	0.0	1.7	1.0
	Scientific	100	97.9	99.0
2. *Which picture shows best where the people live on the Earth?*	Initial	15.2	7.0	3.9
	Synthetic	36.3	31.8	16.5
	Scientific	48.5	61.2	79.6
3. *Which picture shows best where the clouds are?*	Initial	5.0	4.1	1.0
	Synthetic	55.5	34.3	19.4
	Scientific	39.4	61.6	79.6
4. *Which picture shows best what happens when a giant kicks a ball real hard?*	Initial	9.0	11.2	11.7
	Synthetic	48.6	38.8	29.2
	Scientific	42.4	50.0	59.2
5. *Which picture shows best where the trees are on the Earth?*	Initial	23.2	12.4	7.8
	Synthetic	48.4	36.0	27.2
	Scientific	28.3	51.7	65.0
6. *Where is the Sun at night?*	Initial	53.5	25.0	9.7
	Synthetic	22.2	17.4	14.5
	Scientific	24.2	57.4	75.7
7. *What happens when you walk along a straight line for a very long time?*	Initial	6.0	1.7	0.0
	Synthetic	34.3	26.8	17.4
	Scientific	59.6	71.5	82.0
8. *Which picture resembles the Earth best?*	Initial	2.0	1.2	1.9
	Synthetic	3.0	2.1	0.0
	Scientific	94.9	96.7	98.1
9. *Which picture shows best how night falls?*	Initial	59.6	49.6	35.0
	Synthetic	27.3	31.8	32.0
	Scientific	13.1	18.6	34.0
Total:	Initial	19.3	12.6	7.9
	Synthetic	30.6	24.5	17.5
	Scientific	50.1	62.9	74.6

3.6. Breakdown of Mental Models by Age

Detailed data on the frequency with which children chose pictures corresponding to intuitions, conceptual outlines and science-like concepts respectively are presented in Table 7. It summarises the distribution of individual mental models in each age group.

The number of correct ideas about the shape of the Earth, the location of people, trees and clouds on Earth, the force of gravity and the phenomena of day and night increases in children between 5 and 10 years of age. The study also showed the intensity of such changes in children. It turns out that this development is not identical across all the scopes tested with regard to astronomical objects and phenomena. With increasing age, the number of science-like answers increases in the following areas: ideas about the location of people, trees and clouds, determining the possibility of human movement on Earth and the behaviour of objects on the Earth's surface (kicked ball). Parallel to the increase in the number of scientific explanations, the number of children who prefer preliminary and simplified models on the same topics decreases.

These changes apply to all models except for the hollow Earth model. Indications to pictures depicting, e.g., people living in the middle of a hollow Earth, trees and clouds inside the dome of the Earth, remain low (approx. 6–10%) at all studied developmental stages. It seems that imagining a flat space enclosed by a dome makes it relatively easy to explain certain phenomena, such as those related to the force of gravity. It seems that children do not think about the direction of the force (or its source) and rely on information they heard from adults that it was *impossible to fall off the Earth*. Since it is easy to fall off the plane of a disc (after all, it resembles the surface of a table), there must be another image of the flatness of the Earth, which contains a kind of boundary that cannot be crossed. The curvature of a sphere seen on the inside—and creating the impression of a wall prevents a fall from the planet. In this type of reasoning, the problem of gravity is not solved, it is simply eliminated. It is also interesting to note that most references to the flatness of the Earth appear in response to the question about explaining the phenomenon of nightfall. This may be due to a different understanding of the test questions (*Where is the Sun at night?* and *Which picture shows best how night falls?*).

An analysis of children's choices of pictures depicting the shape of the Earth, the location of objects (people and things) and the way they move on the Earth, the relationship between the Earth and the Sun and the phenomena of day and night showed that, with increasing age, there are significant changes in the choice of graphic representations (in the EARTH2 test). The youngest respondents (5- and 6-year-olds) were significantly more likely to choose pictures corresponding to everyday experiences (initial models), while older children were more likely to choose pictures that represented a phenomenon in a more generalised way and linked to a scientific explanation. As children get older, they use less and less intuition and can use more science-like concepts to explain phenomena, whereas the percentages show that more than half of the youngest children display scientific models. Among the oldest respondents, non-scientific mental models persist until the age of 10.

3.7. The Order of Solving Problems in the Process of Forming the Concept of the Earth's Shape

The test questions were designed to address areas where the shape of the Earth poses a significant cognitive problem. In the process of constructing the concept of a spherical Earth, children must resolve each of these problems to build a science-like concept. Research has shown that the number of children who indicate scientific models increases with age. However, since the percentage of indications varies from question to question, their analysis can provide information on the order in which these problems are resolved. It was assumed that if, in a given age group, the percentage of correct answers is higher for one of two questions (problems), it means that children resolved one problem earlier than the other. In this way, by comparing the percentage of correct answers to each of the test questions, it will be possible to determine the order of solving problems in the process of forming the concept of the Earth's shape. The explanation adopted here can be described as a gradual integration of the concept of a spherical Earth into the conceptual structure, which was previously dominated by the concept of a flat Earth.

Three types of questions were included in the analysis: (a) the location of people, trees and clouds, (b) the movement of objects on the Earth's surface (people and a kicked ball) and (c) the day and night phenomena. The percentages of correct answers to all test questions are summarised in Figure 1.

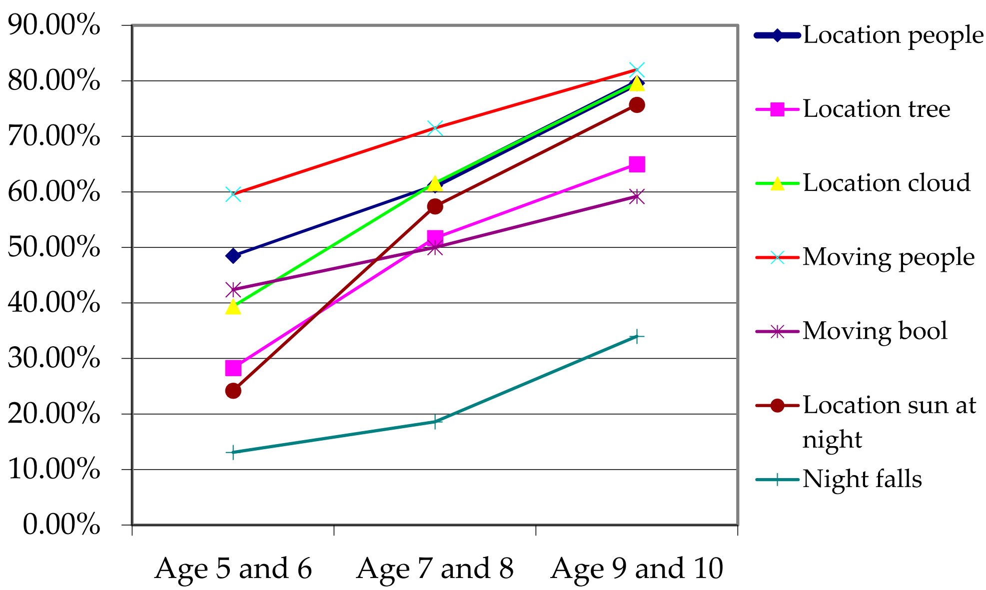


Figure 1. Indication of scientific models in relation to age.

The diagonal lines in the graph show an upward trend in the number of correct indications for all questions analysed. The analysis of the questions concerning locations has shown that, in each age group:

- in explaining the location of people on the Earth, the largest group of children is guided by the belief in sphericity of the Earth. This is probably due to the confrontation of personal experience with knowledge about the consequences of the Earth's sphericity;
- slightly fewer children were able to transfer the conclusion about the location of people on a spherical Earth to the location of clouds in the sky wrapping around the Earth. Perhaps the obstacle is the everyday experience of observing the movement of clouds in the sky, which seems to confirm the intuition about the flatness of the Earth;
- the smallest group of children is able to transfer an inference about the location of people to the location of trees on Earth. This is probably due to the fact that children have rarely (or not at all) had the opportunity to consider the location of trees on the globe.

The fact that trees were the most difficult to locate on Earth, then clouds, with people being the easiest leads to the conclusion that these are the steps by which the children's minds fit the concept of a spherical Earth into their conceptual structure in terms of locating objects on the Earth's surface. It solves the problem of locating people first, then clouds and then trees. This is probably also influenced by images available to children, e.g., pictures of the Earth as seen from space, where clouds surround the blue planet (cultural influence).

Similar results are provided by the analysis of the movement of people and a ball on Earth. Children first construct an image of the movement of people on the surface of a spherical Earth, and then infer the movement of a ball.

In terms of locating the Sun at night and nightfall, there are clear differences. Children first provide a location for the Sun at night, and only later come to understand the phenomenon of nightfall.

Comparing the process of locating objects, their movement on the Earth's surface and the phenomenon of day and night, it turned out that children first come to identify how people move on the spherical Earth and then locate people on the Earth. Next, they also locate clouds, the Sun at night and trees. Finally, they work out how a kicked ball moves. The phenomenon of nightfall is the last item for children in every age group. The explanation described here, however, seems to hold true only for the answers/pictures included in the EARTH2 test. It must be assumed that if the pictures were different or the order of the questions in the test were changed, the results might be different.

4. Discussion

4.1. Development of the Concept of the Earth's Shape

Research conducted among Polish children has shown that all 5-year-old respondents pointed to the Earth in the shape of a sphere, but 2/3 of them gradually give up the spherical shape when explaining the location of people, trees and clouds, as well as indicating the movement of people and a ball, and explaining the phenomenon of nightfall. The number of children who use science-like concepts increases with age. It was also found that non-scientific concepts still persist in 10-year-old children. This confirms previous findings [4,5,34].

It was also found that children first construct the concept of a spherical Earth and then the Earth–Sun relationship. It was assumed that the concept of the Earth's shape is constructed by gradually fitting the concept to the current knowledge structure. The order of resolving cognitive problems was established. It was assumed that problem solving involves re-establishing the location of people and objects on the surface and their movement. It was found that children first solve the problem of how people move on Earth, then their location, as well as the location of clouds, the Sun at night and trees. Finally, children match the way a kicked ball moves on Earth and the phenomenon of nightfall. These data have not yet been established in an acceptable way and need to be verified, especially as the results may be limited by the construction of the research tool and dependent on cultural influences.

The research findings may be relevant in organising educational activities for children to build basic astronomical concepts. Attention to the sequence of problems to be addressed during organised activities may contribute to increased educational effectiveness.

4.2. The Context of Cultural Differences

The context of cultural differences can be observed when the same tools are used with children from different countries. Such a comparison is encouraged by the authors of the EARTH2 test [13]. Unfortunately, as the indications have been grouped solely according to mental models [32] and no distinctions have been made between answers of different age groups to the test [13,31], a detailed analysis of the data is not possible. For this reason, the analysis will be limited to all age groups surveyed. A full summary of the results is presented in Table A1 (Appendix A). The results are presented in the chronological order in which they were obtained.

Shape of the Earth. As for the first question about the shape of the Earth, in a study conducted among Dutch children, 81% chose the spherical shape of the Earth, while 10% of the children indicated the hollow sphere model [13]. In a Greek study, the spherical Earth was indicated by 94.6%, while the hollow sphere model was indicated by 2.2% of respondents [31]. The spherical model of the Earth was indicated by 98.6% of Polish children, and the hollow sphere model was not indicated even once. As regards the control question (8) about the shape of the Earth, in the Dutch study, 81% of children indicated the spherical shape of the Earth, and 5.5% the hollow sphere model. In the Greek study, the results were almost 93% and 5%, respectively, and in the Polish study, 96.6% and 0.5%, respectively.

Location of people, clouds and trees. A similar difference can be observed in questions 2, 3 and 5. In the question about the location of people on Earth (question 2), differences in the number of indications of scientific models are as follows: 44.6% of Dutch children and 54.3% of Greek children and 62.6% of Polish children. As regards the question about the location of clouds (question 3), scientific models were indicated by 45.1% of the Dutch children, 41.8 of the Greek children and 60.8% of the Polish children. As for the question about the location of the trees (question 5), 42.4% of the Dutch children and the same percentage of the Greek children pointed to the scientific model, while among the Polish children, this model was indicated by slightly more than 49.5%.

Movement of a ball and people on Earth. To question 4, almost 40% of the Dutch and 35% of the Greek children pointed to a model where the ball goes around the Earth. In Poland, it was more than half of the respondents (50.5%). In question 7 about the movement of people on the Earth, the difference was the greatest and amounted to 23.9%. For this question, 47.5% of Dutch and 58.7% of Greek children indicated that people can go around the Earth, and the same answer was given by more than 71.4% of the Polish respondents.

Day and night phenomenon. In the question (6) about the location of the Sun at night, 40% of the Dutch and Greek children gave the correct answer, and the same answer was given by 54.3% of the Polish children. As for the control question (9) about nightfall, the results showed the smallest difference. More than 12% of the Dutch children pointed to the scientific model, while among the Greek and Polish children, there were 20.7% such indications.

A comparison of the results of individual test questions showed that differences between the Polish and Dutch children ranged from 7.1% to 23.9% and between the Polish and Greek tests from 0.5% to 19%. A difference of almost 24% is significant. The question may arise whether this is due to the difference in age of the children surveyed. The Dutch study was carried out with children from 4 to 9 years old, the Greek study involved children from 6 to 9 years old and the Polish study involved children from 5 to 10 years old. However, the difference in the average age of the children surveyed seems to contradict this. In the Dutch study, it was M = 7.2, in the Greek study M = 6.9 and in the Polish study M = 7.6. This suggests, therefore, that it is not age but cultural differences that can have such a significant impact on different indications in the test.

It is possible that differences in the results are significantly influenced by education (including home education) or even toys. In Poland, it is rare to find children playing with, for example, a snow globe. A snow globe is a glass sphere filled with water and white pieces of material which, when shaken, resemble falling snowflakes. Perhaps Dutch children are more likely to use these toys and associate their design with the picture in the test depicting a hollow sphere. This may explain why in the Polish study none of the children indicated this model, while in the Dutch study as many as 10% of the children did.

Differences in the EARTH2 test results confirm the effect of cultural influences [6,22–24]. Relatively small differences in geographical location between the countries in which the studies were conducted suggest that actual differences in results may be even greater if more remote countries or those where access to the media is more limited were included. It may also be relevant that the mental models that formed the basis of the EARTH2 test were developed in the 1990s. Back then, children did not have as much access to digital information as they do today. The same may also be true for the consistency of indications of particular mental models. Further research is needed in this regard.

4.3. The Perspective of Knowledge-as-Theory or Knowledge-as-Elements

The main aim of the research conducted to date has been to confirm or refute the existence of mental models. By accepting the assumption of the fragmentarists that mental models should reveal themselves in all test questions, in order to confirm this thesis, it suffices to see how many children in all test questions marked answers relating to the same picture depicting, for example, the Earth as a sphere. Studies using latent class analysis [13,31] clearly indicated that children do not adhere to one shape of the Earth. If only responses to scientific models are considered, then as few as 32 Polish children (7.2%) ticked the scientific model in all test questions. This result was considered to prove a low consistency of mental models and thus the importance of the knowledge-as-elements perspective was raised. However, if in the evaluation of children's test answers/pictures one also takes into account those in which the Earth was presented as a sphere, then it turns out that among Polish children, 30% marked the same shape of the Earth and 5.9%

marked a flat Earth (except in direct questions about the shape of the Earth). This means that almost 36% of all respondents maintain a consistent model of the shape of the Earth.

As the above figure refers to children who presented initial and scientific models, for the remaining children (2/3), it can be assumed that they are in a transitional phase. They start to realise that their existing concepts are insufficient and become insecure in their beliefs [1,34]. They are receptive to information received from adults. However, as they are not yet able to combine it with their personal experiences, they tolerate two different concepts next to each other (dualism). The respected Polish pedagogue and psychologist Stefan Szuman [35] explained that the development of awareness in children progresses from mindless usage of phrases heard from others to a gradual discovery of their meanings. This discovery takes place during the usage of heard expressions. According to Szuman, by verbalising information heard, a child becomes aware of it and by combining it with personal experiences, he/she constructs outlines of concepts. For example, in the test-based study, the question arose as to what extent children were guided by the experience of falling objects (the effect of gravity), and to what extent when choosing a picture they were guided only by their belief in a certain shape of the Earth and intuitions about the location of people and the ball on Earth. It is impossible to provide a clear answer based on the results of the EARTH2 test only. However, in the study in which children modelled the shape of the Earth with plasticine and placed people on it, taking into account the force of gravity, they provided explanations by saying, for example, that *people do not fall because there is this force called gravity which attracts them*. Without being taught about gravity, children intuitively come to understand it. They use the word *gravity* heard from adults to describe the phenomenon of falling objects, guessing that the force of attraction is the cause, although they cannot yet explain its workings in terms of astronomical considerations.

Dualistic views were revealed in situations where children were aware that the Earth was spherical in shape, but their personal experience of the force of attraction (gravity) referred to a flat Earth. They were not yet able to project this force onto a spherical Earth, so they used them separately: differently when the issue concerned the location of people, trees and clouds, and differently when it concerned the movement of people and balls. They used the explanation which was more convenient at the time. In this context, it is important to recognise that dualism of views is evidence that a child is undergoing a change of his or her explanations, which is a natural developmental stage indicative of a child moving from one model to another. Consistency of concepts can therefore not be expected at the transitional stage. This stage of clarification confirms the knowledge-as-elements perspective. As 36% of the examined children showed coherence of views, the remaining children seem to be in a transitional phase.

Linking intuitions to outlines of concepts seems contradictory if considered from the perspective of adult thinking, reasoning at the concrete or formal operational stages (in Jean Piaget's sense). However, it is typical of children in transition from, for example, one of the pre-operational thinking stages to the more mature concrete operational stage. Studies which determined the consistency of children's concepts [13,31] seem to have overlooked the specific nature of synthetic models. As they represent a transitional stage, they are characterised by volatility. In the study using plasticine [28], this volatility was revealed in dualistic explanations, whereas in the test-based study, it may have been revealed in the choice of pictures representing different synthetic models. However, the fact that as many as 30% of children pointed to pictures in which the Earth was depicted as a sphere means that their conceptions were consistent. These findings support the concept of mental models (knowledge-as-theory) and Vosniadou's [21] comments on the application of forced-choice tools, which limit the generation of internal models.

The study seems to confirm both the knowledge-as-theory and knowledge-as-elements perspectives. It therefore appears that both perspectives explain different stages of the same process. Consistent mental models are reflected in concepts based on personal experience (initial models) and those based on scientific knowledge (scientific models). Children presenting these models seem confident in their beliefs [1,34]. The knowledge-as-elements approach, on the other hand, explains an intermediate stage in which children combine personal experiences with information heard from adults. Synthetic models are characterised by uncertainty, when children begin to realise that their current explanation does not work and they abandon it. They seem to construct their explanations by abandoning rigid connections, so to speak, by breaking down knowledge into elements. They accept adult knowledge mindlessly [35] and in the course of processing received information (verbalising, modelling with plasticine, drawing) they solve subsequent cognitive problems, gradually constructing their knowledge. The child's uncertainty about what he or she says decreases as he or she moves towards science-like concepts. The attempt to explain the process of constructing children's knowledge by combining two theories needs to be considered and empirically confirmed, especially as the arguments of the representatives of both approaches seem to be relevant.

5. Conclusions

This paper presents the sequence of cognitive problems that children solve when constructing the concept of a spherical Earth. Attention to this sequence may have important implications for the organisation of effective educational interventions.

Disparities in EARTH2 test results between Dutch, Greek and Polish children point to the importance of cultural influence. This is important, as the forced-choice test has been found to be sensitive to even minor cultural differences. Further research is needed to validate or refute these conclusions.

Moreover, the high consistency of views (36%) revealed by the analysis of the relationship between individual responses in the test is consistent with the findings of Vosniadou et al. (2004) that the use of force-choice tests limits children's choices and narrows the field of inquiry. It was concluded that the assumption made by the authors of the EARTH2 test, that consistency of concepts can only be established if all questions in the test are answered uniformly, seems to be too rigorous. Further research is needed to verify the consistency of children's explanations by assessing more subtle relations between answers in the test. It also seems important to revise views on the development of research tools and the analysis of results.

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Appendix A

Table A1. Percentage of picture choices by age group.

Question	Country	Mental Models						
		Flat Earth		Hollow	Dual	Flattened	No Gravity	Scientific
1. *What does the Earth look like?*	NL	4.5		10.3	2.9	1.3	-	81.0
	GR	1.1		2.2	2.2	0.0	-	94.6
	PL	0.2		0.0	0.9	0.2	-	98.6
2. *Which picture shows best where the people live on the Earth?* (3)	NL	16.1		11.6	-	3.4	24.3	44.6
	GR	12.0		13.0	-	1.1	19.6	54.3
	PL	8.0		5.9	-	1.0	22.3	62.6
3. *Which picture shows best where the clouds are?*	NL	7.7		8.2	-	1.6	37.5	45.1
	GR	9.8		16.3	-	0.5	31.5	41.8
	PL	3.6		3.8	-	0.2	31.5	60.8
4. *Which picture shows best what happens when a giant kicks a ball real hard?*		Falls off the Earth	Does not fall off the Earth					
	NL	8.5	10.1	5.8	-	9.3	26.5	39.9
	GR	7.1	10.9	6.5	-	5.4	34.8	35.3
	PL	2.9	7.9	7.7	-	3.6	27.5	50.5
5. *Which picture shows best where the trees are on the Earth?*	NL	18.3		9.5	-	4.2	25.5	42.4
	GR	12.0		14.1	-	1.1	30.4	42.4
	PL	13.7		7.7	-	1.4	27.7	49.5
6. *Where is the Sun at night?*		Cloud	Sundown					
	NL	15.6	29.6	5.0	-	-	9.0	40.9
	GR	3.8	42.9	7.6	-	-	6.0	39.7
	PL	8.9	19.6	7.4	-	-	10.4	54.3
7. *What happens when you walk along a straight line for a very long time?*		Falls off the Earth	Does not fall off the Earth					
	NL	11.3	9.8	5.8	-	5.5	20.1	47.5
	GR	3.3	9.8	10.3	-	1.1	16.8	58.7
	PL	2.3	6.5	8.1	-	2.0	9.7	71.4
8. *Which picture resembles the Earth best?*	NL	3.2		5.5	5.5	4.7	-	81.0
	GR	1.1		4.9	0.5	0.5	-	92.9
	PL	1.1		0.5	0.0	1.8	-	96.6
9. *Which picture shows best how night falls?*		Cloud	Sundown					
	NL	21.6	38.3	9.2	-	-	18.2	12.7
	GR	10.3	40.8	8.7	-	-	19.0	21.2
	PL	8.8	39.6	5.9	-	-	25.0	20.7

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Article

Young Children's Ideas about Heat Transfer Phenomena

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Abstract: In this article, we present kindergarten children's ideas about thermal phenomena before any educational intervention took place. In order to capture and account for the heterogeneity of the kindergarten group in this study, first teachers observed children's exploration behavior, task orientation, science interest, and language comprehension in everyday kindergarten life using a structured observation form. Then, 24 children aged between 3.8 and 6.0 years were interviewed individually about three situations focusing upon water temperature and its changes. The results show that interest in science and language comprehension are significantly related to children's understanding of thermal phenomena, while task orientation and exploratory behavior are not. In general, the kindergarten children did not yet use the word "heat" in their descriptions and explanations but were more or less able to describe the water temperature and its changes in a differentiated way.

Keywords: kindergarten; children; heat; temperature; ideas; experience

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1. Introduction

The present paper is part of an investigation of the interaction of physical and narrative experience in the construction of concepts by young children in their early encounters with thermal phenomena. Specifically, in this paper, we want to investigate pristine forms of verbal communication by kindergarten children before any deliberate concrete didactic activity has been undertaken and without bias toward particular scientific theories on the topic. We want to ascertain the children's cognitive level and linguistic abilities and, in particular, their spontaneous ability to communicate about simple thermal phenomena. This appears necessary in view of the alternative imaginative and narrative approach to natural phenomena pursued in our research project. Previous studies of children's (verbal) understanding of thermal phenomena can give some indication of what to look for. However, few of them cover very young children, and they are usually not sensitive to the variation of linguistic and general cognitive maturity. Moreover, observations appear to be influenced by expected "scientific" outcomes, i.e., by what temperature and heat ought to mean in a sanctioned approach to traditional thermal science in particular and to physical science in general.

1.1. Experiencing Thermal Phenomena

Children experience and observe natural and technical phenomena in various everyday situations, whether outdoors or indoors, and thus they are also familiar with thermal phenomena already at a young age [1]. Even though the abstract concept of "heat" (you do not see heat) may not yet be pronounced in very young children, they have already had many (indirect) experiences with it, coming from their sense of hot and cold. For example, in winter, large temperature differences can be perceived through the senses: While it is cold outside, it is warm in the heated apartment. It is even warmer in the summer when the sun is shining intensively, and long-sleeved clothing is replaced by short clothing. However, children will also have noticed that in summer, there are places where it is hotter and places where it is cooler. Water temperature in general can also vary. Water can be ice-cold or boiling hot—and there are many gradations in between because water can be heated specifically, but it also cools down. This can be perceived by children, for example, when the parent heats cold water on the stove for making tea and when it is necessary to wait until the hot tea water has cooled down enough to drink it [2]. The hotness sensors in our skin allow us to sense temperature and temperature differences, and in this subjective way, we can also qualitatively determine temperature changes [3].

Objectively speaking, the temperature is a physical quantity (quantified in Celsius or Kelvin scales) that expresses an intensity, i.e., how warm or cold an object is. The temperature can be high or low. As a physical quantity, heat is manifested and experienced indirectly via temperature. Therefore, it is important to understand how the notion of heat as something contained in objects and flowing from object to object can possibly arise—in what sense it can possibly be experienced. The need of the notion of heat arises when processes are observed that unfold over time. An object in contact with another object can become colder or hotter, meaning that heat can be transferred between objects, and doing so, causes temperature changes. The higher the temperature change is, the more heat is supplied or given off. This means that heat can be big or small. In nature, it always flows from an object of higher temperature to an object of lower temperature. Technical devices—such as the electric stove—or natural objects—such as the sun—that emit heat to their environment are called heat sources. In the case of heating water on an electric stove, for example, a certain quantity of heat is supplied to the system (pot with water) over time from the outside (electric stove). At the same time, the pot with water is also in contact with the (colder) ambient: At the beginning, the heat the pot loses to the environment is less than what it receives from the stove, so the temperature goes up. When the two heat exchanges become equal, a dynamic equilibrium is established, and the temperature of the system remains stable. If the water pot is then removed from the stove, the temperature goes down and, after a certain time, reaches the ambient temperature. Without the notion of the concept of heat, it would be impossible to interpret these processes. The process of heating is associated with heat absorption, the process of cooling with heat emission. Thus, heating and cooling are both heat transfer processes.

A more scientific (formal) treatment of heat and temperature is outside the scope of this paper. For an introduction to the foundations of a novel form of physical and narrative experience of nature by children at kindergarten level, the reader can refer to the approach to physical sciences underlying the imaginative course for kindergarten and primary school student teachers described in [4–7].

In primary physics education in kindergarten, the educational focus in the realm of heat is confined to the perception and description of heat transfer processes causing temperature differences, i.e., water and other bodies get warm or cool down. Science education standards in various countries suggest that teaching should address areas of the child's life world where change and dynamics can be observed [8]. For this reason, didactic research needs to focus on questions such as how exactly children experience changes in nature and technical artifacts and how they and their caregivers talk and generally communicate about processes (using natural language or other media at the disposal of young learners). According to learning and instructional psychology, as well as didactic theories concerned with particular topics, the conceptions that children have built up through experience in the everyday world as well as through their engagement with the social world [9–11] should always be taken into account when designing lessons [12,13]. Already Ausubel (1968) stated: "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" [14] (p. IV). Thus, learning situations should be planned in such a way that they are adapted to the learning prerequisites of the students. By connecting to children's ideas and taking their ways of thinking into account, learning in the zone of proximal development can be made possible [10,12,13].

1.2. Prior Observations of Young Children's Ideas about Heat and Temperature

Here, we present an overview of what has been observed and reported in the science education literature with regards to how kindergarten children (and their parents) speak about heat and temperature and related phenomena.

Children's conceptions of heat and temperature have been studied in [15–20]. However, studies of ideas on heat and temperature usually refer to older target groups than those targeted in this article. Only few kindergarten children were investigated on that topic, and some of these few studies are older [21]. Furthermore, it is questionable to what extent such topics are taught in early science education. Even if kindergarten and primary school teachers mention topics on heat and temperature as possible topics of physical science in kindergarten and primary school, they have little affinity for such physical-technical teaching content and are often not confident in teaching it [22–25]. None of the former research reports on ideas about heat and temperature held by kindergarten children are the result of instruction or targeted intervention in kindergarten. In the following, reference will be made to these.

We will first refer extensively to the paper by Albert [26], even though it refers to somewhat older children because it is most useful for our purpose, and it can help in sketching the development of concepts in the course of children growing up. Albert was the first to describe "the development of the concepts of heat in children" (p. 389), but his results are not based on a longitudinal study, and in his survey, children were not confronted with concrete material nor with narratives. In an interview study with 40 children aged four to nine, they were asked for "examples of heat" or "examples of warm" (p. 390). He noted that kindergarten children aged four to six refer in their answers to "hot objects" in one of the following forms: 'X is hot' or 'X makes me (feel) hot' (p. 391)—where X stands for an object that the children named. Especially children between the ages of four and five gave examples like 'The sun is hot', '[The] fire is hot.' (p. 391). Thus, they had an idea of hot objects, but they could not yet distinguish between the object and the property of hotness which means that for young children hot objects are a unit, an "irreducible whole" (p. 391). Even between the ages 5 and 6.6, children "did not talk about heat in objects" (p. 391), but they now direct the word warm or hot not only to the heat source but use it also to express that a heat source makes the child feel hot or warm. More advanced answers, which also occur from the age of five or six years, do not only refer to one's own feeling of warmth, but make it clear that heat sources can also make other objects warm and heat is, therefore, "a very active agent" (p. 392). An example of such a statement would be "The sun makes the air and many other things hot" (p. 391). This "externalization" (p. 392) from the child makes evident that there is an awareness of a movement from the sun to the object and this recognition creates already good preconditions for a mental "distinction between an object and a property" (p. 392) in the context of heat. The idea that hotness is a variable condition in that objects can be or not is found first in statements referring to heat sources that can be turned on or switched off. A child aged 6.6. described, for example, the oven as a heat source and pointed the following out: 'When you turn it on, it is hot, and when you turn it off, it is cold' (p. 392). However, children under seven years still have the idea that heat is something that arises or disappears immediately. The idea of "hot as a process" (p. 393) that takes place over a period of time was not expressed until children were seven to eight years old. Only then they expressed statements like 'it gets hot' or 'it warms up' (p. 394). The process of heating is described either from the point of view of the heat source or the object to be heated. The former would be the case with statements like 'The sun shines and warms [the air] up', the latter with statements like 'The water gets hot' (p. 394). Furthermore, at this age, the word 'heat' sometimes appears, which suggests that children begin to differentiate "between the object of hotness and heat in the object" (p. 394), which can also be emitted. They develop the idea that "heat is something active in the object being warmed" (p. 394).

In a study by Hadzigeorgiou [21], the idea of heat as an invisible substance was detected in children aged six or seven, but only occasionally and certainly not in most children of this age group. A child explained, for example, that "there is something that moves from the hot body into my hand when I touch it" (p. 72). It is also worth mentioning that children assume that 'heat' and 'cold' are two separate invisible substances. For example, children stated that 'heat is radiated from a stove' as well as 'cold is radiated by a piece of ice' (p. 72). In a study by Piaget and Garcia [27], heat transfer phenomena were treated with the help of concrete examples. Children of different ages were shown an experiment in which a steel ball was heated and then thrown into cold water. It was found that the idea of heat as transmission from a warmer to a colder object developed rather late, i.e., only at the age of 12. Children under seven years capture the warming of an object independently of the cooling of the hotter object and thus do not have an idea of thermodynamic equilibrium.

From databases, Luce and Callenan [2] analyzed several naturalistic parent-child conversations in which heat and temperature were the subject matter. The authors investigated how and in which contexts heat- and temperature-related concepts were talked about. In these conversations, all children were aged under six years and no gender differences were evident. The results show that everyday contexts in which words related to heat and temperature occur were mainly conversations during food preparation or during the meal itself (e.g., when waiting for food to get warm or cold), during conversations about the weather (e.g., when comparing the temperature inside and outside) and one's own body temperature (e.g., when a person feels cold or gets warm) (p. 12). In most cases of the 1460 statements recorded in these contexts, heat and temperature related words were used as an adjective to express a "property", for example: 'That is a hot tea', 'The sun is hot', 'My hands are cold' (p. 6). Some statements were related to temperature change processes as well and were classified as "vague process", meaning that such expressions refer to heating and cooling in an overall sense without mentioning the word "heat". For example: 'We have to wait for it to heat up', 'It is getting warmer', 'you do not want to get cold' (p. 6). Only sporadically heat was mentioned explicitly. Luce and Callenan concluded from this study that "the word heat occurred rarely in these conversations, which suggests that children may actually be getting very few opportunities to hear about how adults conceptualize the concept of heat in everyday talk" (p. 8). However, we must draw a distinction between conversations of parents with very young children and somewhat older ones. With children aged between 2.0 and 3.5, parents used heat- and temperature-related words almost always "as properties of objects" (p. 8), while with children aged between 3.5 and 6.0, they talked "about properties and vague processes with similar frequency" (p. 9). All in all, it can be stated that the words hot and cold were the most frequently mentioned words in natural conversations, and many of these talks referred to "objects that can and do change temperature" (p. 13), but without thematizing why objects get hotter or colder.

Regarding the naming of the temperature of objects, there is evidence that already at an early age, i.e., from two years onwards, children can distinguish clearly between the extremes cold and warm (respectively hot) whose conceptualization is based on sensorial experience in which they have felt warm or cold [28]. However, children aged between four and seven use both terms, hot and warm, often synonymous, and thus do not yet differentiate between different temperature levels [26,29]. In a study by Qonita and colleagues [29], for example, children aged four to six were presented with three water glasses with different temperatures (cold, warm, hot). Even though the three glasses were named correctly and thus the different temperature levels were well distinguished, not all children succeeded in later describing the mixture temperature between the cold and hot water as warm, but often used the term hot. Likewise, they did not differentiate between the terms cold and tepid. Thus, when comparing two temperatures, they use the term 'cold and warm' rather than 'cold and tepid' or 'tepid and warm' even if the temperature difference between the two objects was not that great.

For children, estimating temperature is challenging, and its success depends on the kind of comparative task. For example, indirect proportional tasks are very demanding. In a study [30], children were asked to predict the temperature of two different amounts of water (a half-full and full water glass) when they were heated for the same time with the same number of candles (one candle per glass). The results show that only children starting at the age of nine years were able to make correct judgments about the temperature of these two amounts of water, saying that the temperature in the half-full water glass would be higher. Younger children, aged between four and eight years, gave mostly incorrect answers, namely that the water temperature would be the same. However, already kindergarten children (from about five years) were able to understand the rule "more A, more B", for example, the more candles warm the water, the higher the water temperature.

It is worth mentioning that there are a number of papers in the literature on heat-related phenomena, like thermal expansion [31], thermal conduction, and conducting/insulating materials [32,33], melting, evaporation, phase states of water [34], as well as investigations of children's familiarity with thermometers, thermal scale, and temperature representation [20,35,36]. All these papers are biased by the investigation of the ability of children to describe, predict, and interpret heat-related phenomena, and the issue of children's conceptualization of heat and temperature changes is not dealt with.

1.3. Research Aims and Questions

In this paper, we want to bring out the conceptualizations of heat transfer phenomena of a kindergarten group and present the statements and interview performance of individual children as descriptively as possible. To this aim, we investigated how young children perceive and judge different phenomena in contexts of everyday life. To be more precise, we explored kindergarten children's verbal communication concerning the heating of water by sunlight, the heating of water on a stove, and the cooling of water in a hot-water bottle. The ideas that were collected are to be understood as an expression of spontaneously developed understanding that may or may not have been enriched by extracurricular activity rather than learned as a part of prior lessons. Our report is an inventory of children's understanding, upon which basic didactic interventions can be developed.

In contrast to previous studies, this study takes account of the heterogeneity of kindergarten children. Our investigation is done with kindergarten children—from a rather heterogeneous cohort, both with regard to developmental age (between three and six, almost every month counts) and linguistic background. Thus, in this study, not only age is considered (as has been done in previous studies), but also other relevant areas of children's development as well as their (different) linguistic abilities. This seems reasonable and necessary because it is known that children also differ in their characteristics of different developmental areas, which could possibly also influence the grasp of the child's conceptions as well as the child's conceptual development. First of all, it must be stated that linguistic ability is a central factor because it is not possible to directly collect children's ideas, but only children's statements, i.e., representations of mental ideas [13]. Therefore, knowledge can never be clearly separated from the ability to describe phenomena in language [1]. Since thinking and language are inseparable, language also plays a central role in the development of higher forms of thinking [37]. In addition to language, it seems important to survey children's task orientation, because this ability shows how goal-oriented children are in mastering tasks, whether they are easily distracted or remain focused and persistent on a task [38]. A low task orientation could distort the results of the preconcept survey. Children also differ significantly in their exploratory behavior, i.e., in the way they deal with new and unknown things and situations, whether they explore the environment independently, how optimistically they approach new tasks, or whether they are rather hesitant [39,40]. It is obvious, for example, that shy and inactive children will have different experiences than active children who are open to new situations [41].

Exploration creates knowledge structures, i.e., the child learns by exploring the world [42]. Through interaction with the environment, a more domain-specific inquisitiveness and interest will develop over time. For example, scientific interest manifests itself in an active exploration and questioning of natural phenomena [39,40]. This domain-specific interest leads the children to acquire knowledge increasingly in this domain [43,44], and it could be assumed that children with a high interest in science also have more experience and knowledge in this area and that they will show a higher willingness to try to deal with science questions and activities [45].

In conclusion, in our study, we focused on the following research questions:

- how do kindergarten children grasp heat transfer phenomena?
- to what extent do they correctly estimate, predict, or even explain temperature differences or changes in various situations?
- what is, apart from age, the role of children's developmental areas like exploratory behavior, science interest, task orientation, and language comprehension?

2. Materials and Methods

2.1. Research Design

According to the research aims, an exploratory approach was followed in this study. Since young children's ideas should be explored in detail to obtain a deeper understanding of their thinking, only a small sample of kindergarten children could be investigated (we are aware that limitations of the generalizability of the results had to be accepted). This study involved a naturalistic environment and was conducted with a standardized observation instrument and a semi-structured interview technique. The use of both quantitative and qualitative methods makes it a mixed-methods study, but it must always be considered first and foremost as a case study [46,47]. The sampling and data collection procedure are explained below.

2.2. Procedure

The sample was recruited from a kindergarten in the province of Bolzano (Italy) where children from three to six years learn, play, and interact together and, due to territorial characteristics, have heterogenous mother tongs. With the school principals' permission and thanks to the teachers' cooperativeness, teachers at that school collaborated in this study by taking over the data collection. As children's caregivers, they could observe and interview them in a familiar environment. For the validity of the study results, it was beneficial that the kindergarten teachers collected the data. The assessment of children's behavior, interests, and abilities, for example, requires a long period of observation and knowledge of each child. The kindergarten teachers are those who see the children every day and know the whole kindergarten group and its individuals best. If the observation and rating had been carried out by an outsider, the risk to observe and not correctly distinguish non-typical from typical scenes would be greater and the validity of the observation doubtful, as the outsider would not have the same observational material available and thus the expertise for conducting the rating assessment would be limited [46–48]. Observation is one of the professional activities of kindergarten teachers, and several observational instruments are specifically designed for this professional group [48,49]. Also, the interview was conducted by the teachers and not by researchers. It is known that young children have difficulties in forming interpersonal relationships with strangers [50] and that shy or inhibited children have difficulties expressing themselves in interviews [51]. "Many researchers have commented on the difficulty of engaging young children in the interview process" [52] (p. 2) and emphasize that children must "feel comfortable" [53] (p. 354). Therefore, a person with whom a secure attachment relationship exists was used as the interviewer, namely the kindergarten teacher as a kind of secondary caregiver. In this way, the results of interviews should be collected in a manner and an environment that does not suppress children's thoughts by an alienating situation. Generally, the method of interview has the advantage that an exchange between interviewer and child is possible, and thus, the validity of the statements is increased by the possibility of asking how something is meant [54]. However, in the literature [52], interviews with very young children are considered "a significant challenge" (p. 1), and it is emphasized that the "child-adult interaction is central to these challenges" (p. 7). To standardize the observations and interviews as much as possible, the teachers were given the questions and illustrative material for the interview with the children and were briefed in detail on how to use the observational instrument and data collection techniques. Before starting the investigation, parents were informed about the planned study by an informed consent document and were asked to submit their signed consent to the teacher. Only those children who had parental consent were included in the study.

The teacher collected all the data and assigned each participating child a case number. Participants were first observed by predefined aspects of their behavior, abilities, and interests (see Section 2.4) during daily kindergarten life with free and structured activities in and outside the classroom. After several weeks and before conducting the interviews, two teachers of the kindergarten group independently completed a structured observation sheet for each child. Then, a consensus rating of both teachers was used for analyses to improve the quality of the assessments. The interviews (see Section 2.5) took place during the morning time in a separate room at kindergarten. Thus, the interviews could be carried out undisturbed in a familiar environment. The room was prepared with the illustrative materials to be used during the interview. Additionally, a video camera and audio equipment were prepared to record the interviews. The teacher conducted the interviews with all children individually and created an atmosphere as natural and trusting as possible. The children were informed that the teacher wants to explore different situations and is interested in knowing what they think about them. During the interview, care was also taken to ensure that children themselves showed willingness to participate, otherwise, it was stopped, or some interview questions were skipped. In total, an interview took approximately eight minutes.

The sample composition as well as the technique, materials, and contents of the observation and the interview are now described in more detail.

2.3. Participants

All participants of this study were part of a heterogenous kindergarten cohort in an Italian kindergarten institution of the province of Bolzano. Children with sufficient language comprehension in Italian were included in the sample. Due to COVID-19 quarantine measures during the survey, not all children could participate. In total, 24 kindergarten children—17 girls (70.8%) and 7 boys (29.2%)—were interviewed. On average, they were 4.9 years old (SD = 0.89): Half of the children (50%) were aged between 3.8 and 4.7 years, and the other half (50%) between 5.2 and 6.0. Italian was the mother tongue of 12 children (50%) and the second language of the other 12 children (50%). In both age groups, composed of 12 children each and aged either over or under 5 years, there were 6 children (25%) with Italian as their mother tongue.

2.4. Observation

To provide structured information about the behavior, abilities, and interests of the children who were interviewed, the following scales of the standardized observation sheet KOMPIK [39] were used: Exploratory Behavior, Science Interest, Task Orientation, and Language Comprehension. The KOMPIK instrument can be used to systematically observe kindergarten children aged between 3.5 and 6.0. The assessment should be made after an observation period of several weeks on a 5-point Likert scale (1 = low level, 5 = high level). With the four selected KOMPIK scales, kindergarten teachers had to assess a total of 24 statements for each child. The first scale Exploratory Behavior captures how curious and inquisitive the child generally is and how open-minded a child is in exploring unknown things and situations. The second scale, Science Interest, focuses on the area of natural sciences and describes how active and interested a child is in exploring and investigating natural phenomena. The third scale, Task Orientation, indicates the extent of how well a child can complete tasks in a goal-oriented and concentrated manner. Finally, the scale Language Comprehension shows the level of the child's ability to implement calls to action and answer questions appropriately [39,40].

The KOMPIK observation instrument was designed especially for kindergarten teachers and can be used with children who are well known to pedagogical professionals. The assessment of a child's behavior, interests, and abilities does not occur in a direct observational situation but from memory based on several observations. These observations should be made as part of the regular kindergarten routine without creating special (test) situations [41].

KOMPIK is a scientifically validated observation tool developed in collaboration with scientific experts and educators from the field. The content validity is given by expert assessment and confirmed by external validation. Some KOMPIK scales show, for example, significant correlations (from 0.28 to 0.47) with Petermann's, Stein's, and Macha's [55] development test for children from 6 months to 6 years (ET 6-6) which indicate a convergent validity of the instrument. According to the authors of the observation sheet, the KOMPIK scales have high reliability in the sense of internal consistency. Furthermore, the retest reliability evidenced scores between 0.90 and 0.96 and the interrater reliability scores between 0.74 and 0.92 [56]. Nevertheless, the KOMPIK authors recommend that kindergarten teachers discuss their assessments of each child [40].

2.5. Interview

A semi-structured clinical interview was carried out to gain insights into young children's prior knowledge and ideas about the concepts of temperature and heat. This qualitative interview procedure is characterized by careful questioning aimed at gradually eliciting ideas [57,58]. The interviewer adopts an interested, questioning attitude and encourages the children to give an answer, but does not correct them [13]. An interview guideline, in which topics and questions are defined in advance, served to structure the interview and enabled later comparisons between different participants [59]. Nevertheless, this interview technique allows enough openness in questioning. Thus, the language and question design can be adapted to the level of the respondents, which is particularly important with younger children [60]. According to Bierman [61], children could have difficulties "in expressing ideas in an open-ended interview format", while "they may be able to communicate their thoughts through tasks that require less complex response options" (p. 232). Interviews with young children should, therefore, be well structured with small-step questions.

The study's interview addressed heat transfer phenomena and included three concrete situations for which several questions were asked. Each situation was introduced with stimulus material, which should not only motivate the children to express their ideas but also help them to comprehend the situation better [58]. The order in which the questions were set was clearly defined and could not be changed by the teachers. Likewise, the teachers were not allowed to resolve the individual questions in order not to influence the child's response behavior for the next questions. Now, the three situations are presented together with the corresponding questions.

The initial situation, "Water in the sun, water in the shade", drew on experience (e.g., children have experienced that it is colder in the shade than in the sun in summer) and had to capture whether the child could identify the sun as a heat source and estimate its influence on the water temperature. For this purpose, the teacher presented a picture showing one glass with water standing under a tree and another glass with water standing in the sun. The interviewer asked the child to estimate the temperature of the water in both glasses: "Is the water in one glass warmer than in the other? If so, which one and why?" After providing an estimation, the child could check it. Therefore, the teacher placed two water glasses on the table, one with lukewarm water (with a sun symbol to make it clear that this water was in the sun) and one with cold water (with a tree symbol to symbolize that it was in the shade). The children had to feel the water and describe its temperature in both glasses and, finally, try to explain why it differed, asking, for example, "Why is the water in the sun warmer than the water in the shade?"

In the second situation, called "water cooking", another familiar (but now controllable) heat source—the stove—was highlighted to investigate whether the children could already estimate the influence of different levels of heating power on the water temperature. In addition to directly proportional relationships (the higher the power of heating, the faster the water boils), an indirectly proportional task was set to find out whether they were aware that the temperature change also depended on the amount of water to be heated (the less water in the pot, the faster the water boils). At the beginning of this sequence, it was ensured that the child understood how a stove works. Therefore, a toy stove was presented, and the child was asked to demonstrate what to do when heating a pot of water. The child had to put it on the stove and turn the stove on. Once the cooker was "turned on", the child had to try to explain why it could make the water hot. Specifically, they were asked, "Why does the water heat up when it is on the stove?". Then, more specific questions were asked while demonstrating these situations repeatedly on the toy cooker. The child was asked, "What happens when the stove is turned on only halfway and not fully? Does the water boil faster if you turn the stove fully or halfway? Why?" The child was also asked what would happen when the stove was turned on fully, but the amount of water in the pot was different: "Where does the water warm up faster: In a pot with more or less water? Why?"

In the third situation, called "the hot-water bottle", the child was confronted with a warm hot-water bottle—a container of hot water that radiates heat and by so doing loses its ability to heat over time. First, the interviewer had to determine whether the child was familiar with a hot-water bottle and its functionality (i.e., heat transfer). The child could feel and hold the hot-water bottle and guess what might be in it—namely, hot water. Then, the child was asked whether the water bottle keeps you warm even with cold water in it. The child should also try to provide a reason for his or her answer. Finally, the child was asked what would happen if the hot-water bottle with hot water was left for a while: "Is the water in the hot-water bottle after a while still hot, or does it change? Why?" The aim was to find out whether children were aware that a warm hot-water bottle is only a temporary source of heat and that its temperature falls due to heat dissipation.

2.6. Data Analysis

All data were available in anonymized form and were entered into a sav-data-file created in SPSS 27. For the general description of the sample, data on age, gender, and mother tongue were analyzed.

Before considering the observational data for analyses, the reliability of the KOMPIK scales composed by the raw data of the two observers was checked: For each KOMPIK scale, the interrater reliability was evaluated considering the Interclass Correlations and interpreted according to Cicchetti [62]. The degree of agreement among the two observers who assessed children's behavior, interests, and abilities could be considered fair to excellent for the scales Science Interest (0.53), Task Orientation (0.82), and Language Comprehension (0.90) with the exception of the scale Exploration (0.32), which evidenced a poor Interclass Correlation. For further analysis in this study, a consensus rating of the two observers was used. Thus, from the combined assessment of the statements of the KOMPIK observations sheets, the four scales Exploratory Behavior, Science Interest, Task Orientation, and Language Comprehension, were formed for each child. The calculated mean scores of the scales determined children's level in the areas listed above, where a score of 1 was low and a score of 5 high. It was also important to consider children's age when interpreting their mean scores since younger children generally have developmentally related lower scores than older children. For this reason, the mean scores and standard derivations were not only made evident for the entire group but also separately for two age groups formed.

The video-recorded interviews were transcribed by the teachers, taking care that data was anonymized and that the transcribing teacher was not the interviewer one. In the transcripts, the teacher's and the child's statements were recorded verbatim. Non-verbal information in the video records was only noted if relevant to the content—for example, if an answer was provided by nodding or pointing to a picture or material. By reviewing the transcripts, it was also possible to determine that the teacher adhered to the interview rules. Due to the structured interview procedure involving three situations, all interviews could be divided into three sequences. For each sequence, the children's answers to the various questions were categorized and finally illustrated with examples from the interviews. In addition to qualitative data analysis, answers were categorized more generally to allow quantitative data analysis. Thus, qualitative data were quantified using the same category system for each interview content. The numerical category system formed determined the extent to which a content has been grasped by the children: 2 points were provided for a correct prediction with a plausible explanation, 1 point for a correct prediction without a plausible explanation, and 0 points if the prediction was wrong or if no idea was expressed at all. Individual questions that the interviewer did not ask a child were not scored. The frequencies and valid percentages were calculated for all categories (not solved, predicted, explained). To represent the whole interview performance of each child, an average score was calculated from the points achieved for their answers to all questions they were confronted with.

Due to the small sample size, only nonparametric tests were used in bivariate analysis. For correlation analysis, Spearman's rank correlation coefficients were calculated, which required only ordinal scaled data and provided information about the relationship of variables. The significance tests of Spearman's rank coefficients also had the advantage that they are more robust than significance tests of parametric correlation coefficients. Likewise, the partial correlation analyses were conducted with Spearman's correlation coefficients. The method of partial correlation was used to describe the relationship between the KOMPIK variables and the interview performance whilst controlling, i.e., taking away the effect of age.

3. Results

3.1. Participant's Behavior, Abilities, and Interests

The results of the KOMPIK observations sheets produced the following score range: Between 2.2 and 4.3 on the Exploratory Behavior scale, between 2.1 and 5.0 on the Task Orientation scale, between 2.8 and 5.0 on the Language Comprehension scale, and between 1.4 and 5.0 on the Science Interest scale. All means and standard deviations are shown in Table 1 for both the sample and the two age group subsamples.

Table 1. Means (standard deviations) of the sample's behavior, abilities, and interests (n = 24)—also differentiated by age group.

KOMPIK Scales	Sample *M* (*SD*)	Aged < 5 [1] *M* (*SD*)	Aged > 5 [1] *M* (*SD*)
Exploratory Behavior	3.60 (0.58)	3.44 (0.74)	3.77 (0.32)
Science Interest	3.86 (0.86)	3.34 (1.01)	4.27 (0.44)
Task Orientation	3.27 (0.69)	2.95 (0.51)	3.60 (0.72)
Language Comprehension	4.04 (0.67)	3.72 (0.73)	4.37 (0.43)

[1] Aged < 5 = Subsample with children aged under 5 years (n = 12); Aged > 5 = Subsample with children aged over 5 years (n = 12).

3.2. Interview Answers

In the following sections, participants' answers to the interview questions are described in detail, and the valid percentages of the response frequency are provided in each case. Accordingly, questions that were not individually posed to children were not considered.

3.2.1. Answers Referring to "Water in the Sun, Water in the Shade"

Seventeen children (70.8%; $n = 24$) could correctly predict that the water placed in the sun would be warmer than the water placed under a tree. The children mostly described the situations one by one, for example: "This is warm, this is cold". Four children (16.7%) first assumed that the water in the sun would be cold but changed their answers to "warm". Three children (12.5%) stood by their opinion that the cold water was in the sun without explaining this further.

When asked why the water in the sun is warmer, 17 children (70.8%) provided one of the following answers: "Because the sun is warm", "Because the sun warms it up", or "Because it is in the sun, it warms". Thus, the children referred in their answers to the sun as a warm source. Four children (16.7%) with correct predictions gave no explanation.

On the other hand, when asked why the water under the tree is cold, seven children (29.2%) justified this simply with the fact that the water glass is in a different place, for example, they replied, "Because there is the tree" or "Because it is under the tree" but could not explain their descriptive answer further. Two children (8.3%) gave only the one-word answer "cold", and one child (4.2%) could not provide a reason. Those answers were evaluated as correct predictions without explanations.

The following dialogue shows an advanced answer of a child who contrasts the different locations in his attempt to explain:

Interviewer: "Why is this water cold?"

Child: "Because it is in the shade".

Interviewer: "Why is the water in the shade cold and the water in the sun warm?"

Child: "Because it is cold in the shade, while in the sky, the sun is warm".

Moreover, other children mentioned that the water is cold, "Because the tree makes shade". The children often believed that the water under a tree's shade cools down or gets colder and not necessarily that the water does not get warmer while the sun is missing. This assumption is reflected in the two following statements: "In the shade, the water becomes colder", "It is becoming cold because it is in the shade". Some of the answers to the question of why the water under the tree was cold referred to a specific activity that allegedly took place there: "Because the ice is coming", "Because the cold is coming", "Because the tree makes it colder", "Because the leaves ... they are making wind", or "Because there [in the tree] is wind". As "explained" were classified those answers of children who found a plausible explanation, even if it was not entirely accurate. The answers of 11 children (45.8%) were scored as "explained".

3.2.2. Answers Referring to "Water Cooking"

In the second sequence of the interview, a toy stove and a toy pot with water were presented. Almost all children, namely 22 (91.7%; $n = 24$), were aware that they had to turn on the stove to bring the water to a boil. The following dialogue shows the best answer to the question of why the water gets hot:

Interviewer: "What does it happen when the cooker is turned on?

Child: "The water boils. It gets even hotter".

Interviewer: "And why does it boil in your opinion?

Child: "It boils because the stove is hot".

Interviewer: "What makes the water boil?"

Child: "The one where you cook".

Interviewer: "Why does the water heat up if it is on the stove?

Child: "Because it is hot underneath. And above is the pot. The heat comes and makes it boil".

The word "heat" was used here for the first and last time. This child did not only identify the stove as the source of heat but referred also to the movement of heat from the stove to the pot of water. Apart from this one child, three other children (12.5%) explained the cooking of water referring in their answer to the stove, for example: "Because of the stove, the pot gets hot" or "The stove is getting hot" and "The stove—it heats up". One of them added the following comparison: "Then, the same thing happens as with the sun. It gets hot there too". Children's descriptive answers considering only the water temperature (e.g., "It gets warm") were not rated as explanations because the stove was not included in this consideration. Answers that described the effect of cooking, but not the heating process were also not evaluated as explanation, for example: "Then you can put something in it so that you can cook" or "To make pasta".

In the following, the children were asked to estimate what happens with a pot with water when the stove is turned on only halfway and not fully. Correct predictions were provided by 18 children (81.8%; n = 22) in the form of the following answers: It boils "later" or "it boils a little bit later", as well as "it boils a little" or "then it gets medium hot". While the first two of these answers refer to a longer period needed for warming up, the last two answers express different levels of temperature that would be reached. Asked for reasons, the four children (18.2%) who answered responded as follows: "Because you only have a small flame" or "Because you have to wait". Wrong predictions, such as "It takes less time" or "It boils first", were provided only by three children (13.6%) and were also not justified.

In the last phase of this sequence, where the boiling of water (with the same heating power, that is, with the stove fully turned on) was compared for different amounts of water, the children's opinion was divided: nine children (47.3%; n = 19) correctly assumed that water boils faster "where there is less water" but could often not justify this assumption ("I do not know"). Only six children (31.6%) could give a simple justification, for example: "Because there is less water in it". Wrong predictions, such as that the container "where there is more water" would boil faster, were mentioned by 10 children (52.6%) and thus almost equally often as the correct answer. The latter children could not provide any reasons ("I do not know").

3.2.3. Answers Referring to "The Hot-Water Bottle"

The interview answers indicate that 17 children (73.9%; n = 23) were not familiar with the hot-water bottle, whereas six children (26.1%) were able to describe its function, as the following example shows: "When you are cold, you put warm water in it, and you put it on yourself—it warms you". Frequently, the functionality of the hot water bottle was associated with stomach aches: "I use it when I have a stomachache—it warms my stomach". Based on previous knowledge or tactile sensation in the interview situation, almost all children (95.6%) could describe the hot-water bottle as warm and containing hot or warm water. Only one child (4.3%) said that the hot water bottle was "cold".

When asked whether the hot-water bottle would also warm when it contains cold water, 18 children (78.3%; n = 23) answered correctly that this was not the case. The provided reasons were relatively simple: "Because it is cold" or "Because it does not work with cold water". Sometimes, in their explanations, they made comparisons between cold and warm water: "If you put cold water in here, it is cold. If you put warm water in there, it is warm" or "It does not warm because the warm water is stronger than the cold water". Some children referred in their answer to a hypothetical effect that cold water would produce: "If you put cold water in here and you put it on, you will be ill even more", "The hand will cool down" or "The body will freeze". Eight children (34.8%) could not provide any reason for their correct prediction. Wrong prognoses, namely that the hot water bottle would also warm with cold water, were expressed only by five children (21.7%). Two of them later revised their answer to a "no".

In the last interview question, when asked whether the hot-water bottle filled with warm water would still be warm after a while or whether something would change, 14 children (63.6%; n = 22) correctly answered that the hot-water bottle would then be "cold" or would "become cold" or "a little bit cold". As the reason for cooling down, most children simply cited the waiting time: "Because if you wait, it becomes a little bit cold". In a few answers, it became clear that cooling takes time and involves several temperature gradations: "It is hot, and if we wait a bit, it starts to get cold". One child expressed explicit different gradations of temperature:

Child: "It is getting colder, colder and colder, freezing".
Interviewer: "Why?"
Child: "Because there is not new water flowing in here".
Interviewer: "No new warm water? And if you do not warm it?"
Child: "Then it gets cold".

In total, only four children (17.4%) came up with a plausible, more profound explanation. Many unspecific or wrong answers were provided as a reason for the cooling of water, such as, "Because there is water in it" or "Because there is shade". Eight children (34.8%) could not make even a correct prediction. Most of those children said, for example, that the hot-water bottle would still be "warm" or "still warm" even after a long time. When asked why, no reasons could be given. One child mistakenly assumed that the water would "boil" after waiting for a while and probably used statements from the previous situation involving the cooking of water. One child said that he or she did not know what would happen.

3.3. Solution Frequency

In the interview, children were generally more able to give a correct prediction about the water temperature or temperature change of water as to find an explanation for why this is so or why this is happening. However, the solution frequency varied depending on the content of the interview. Table 2 shows for each interview content the number of children who could not give an answer to a question (not solved), who were able to give a correct prediction, and who were also able to give an explanation. Since the interviewer did not set every question for each participant, the sample size (n) was smaller for some question contents.

Table 2. Solution frequency of all questions.

Questions Referring to ...	n [1]	Not Solved [1]	Predicted	Explained
Warm water in the sun	24	3 (12.5%)	21 (87.5%)	17 (70.8%)
Cold water under the tree	24	3 (12.5%)	21 (87.4%)	11 (45.8%)
Water heating on stove	24	2 (8.3%)	22 (91.6%)	4 (16.6%)
Halfway turned-on stove	22	4 (18.2%)	18 (81.8%)	4 (18.2%)
Less water heating on stove	19	10 (52.6%)	9 (47.4%)	6 (31.6%)
Water bottle with cold water	23	5 (21.7%)	18 (78.3%)	10 (43.5%)
Hot-water bottle after a while	22	8 (36.4%)	14 (63.7%)	4 (18.2%)

[1] n = number of children who were confronted with this question; not solved = answer was wrong, or no answer was given.

Most children had difficulty answering questions regarding the prediction of the content "Less water heating on stove" and "Hot-water bottle after a while". Here, the number of children who named an incorrect solution is comparatively high, and the number of children who were able to give a prediction is comparatively low. In contrast, the questions referring to predictions about "Water heating on stove", "Warm water in the sun", "Cold water under the tree", and "Halfway turned-on stove" were solved correctly by more than four-fifths of the children. From the explanation questions, most children correctly answered those of "Warm water in the sun". Only a few children could find an explanation for questions in the content "Water heating on stove", "Halfway turned-on stove", "Hot-water bottle after a while", and "Less water heating on stove".

3.4. Participant's Interview Performance

The interview performance indicates how well the children mastered the three interview situations overall. The highest possible mean score of interview performance was 2.0, and the lowest 0.0. From the sample, 75% of the participants (18 children) achieved a score greater than 0.6, 50% (12 children) a score greater than 1.14, and 25% (6 children) a score greater than 1.43. Each participant's individual score is shown in Figure 1. The lowest score of the participant's interview performance was a mean of 0.29, and the maximum score was a mean of 1.86. The average sample's interview performance is given by a mean score of 1.11 and a standard deviation of 0.49. As Figure 1 shows, the distribution of interview performance across the age groups is quite heterogeneous, although there are tendencies for lower performances among younger children (see also Section 3.5.2).

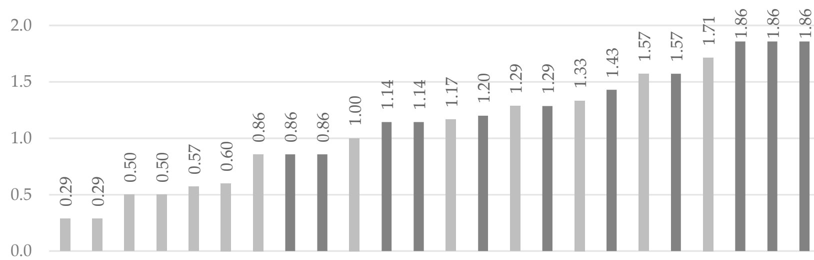

Figure 1. Overview of the interview performance (mean) of the single participants (n = 24). The color of the bars indicates their age group (grey = aged under 5 years; black = aged over 5 years).

3.5. Results of Bivariate Analysis

3.5.1. Correlations: Behavior, Abilities, Interests, and Age

In bivariate analysis, the different KOMPIK scales evidenced partly significant, partly not significant correlations with children's age: Task Orientation correlated significantly with age (r_{sp} = 0.48; $p < 0.05$), as well as Science Interest (r_{sp} = 0.47; $p < 0.05$). The variable Language Comprehension showed a tendency to a significant correlation with age (r_{sp} = 0.40; $p < 0.10$), whereas Exploration did not correlate significantly with age (r_{sp} = 0.20; n.s.).

3.5.2. Correlations: Age and Interview Performance

The calculated correlation by Spearman shows a tendency but not a significant correlation between Age and Interview Performance (r_{sp} = 0.36; $p < 0.10$).

3.5.3. Correlations: Behavior, Abilities, Interests, and Interview Performance

When the different KOMPIK scales were related to children's Interview Performance, it became evident that some KOMPIK scales correlated while others did not: Science Interest correlated very significantly with Interview Performance (r_{sp} = 0.66; $p < 0.01$), and Language Comprehension correlated significantly with Interview Performance (r_{sp} = 0.51; $p < 0.05$). Task Orientation did not correlate significantly but showed a tendency to a correlation with Interview Performance (r_{sp} = 0.36; $p < 0.10$), neither did Exploration correlate with Interview Performance (r_{sp} = −0.05; n.s.).

3.5.4. Nonparametric Partial Correlations: Behavior, Abilities, Interests—Controlled with Age—And Interview Performance

In the calculations of the nonparametric partial correlation, all scales of KOMPIK were included that correlated with Interview Performance. Age was used as a control variable.

Controlled with Age, again, a very significant correlation was calculated between Science Interest and Interview Performance ($r_{sp\ \text{controlled by age}}$ = 0.60; $p < 0.01$). Without the influence of Age, Language Comprehension still correlated significantly with children's Interview Performance ($r_{sp\ \text{controlled by age}}$ = 0.51; $p < 0.05$). Task Orientation, controlled by Age, did not correlate with Interview Performance ($r_{sp\ \text{controlled by age}}$ = 0.23; n.s.).

4. Discussion

The aim of this study was to explore kindergarten children's ideas about thermal phenomena with a focus on water temperature and changes caused by heat transfer. In the context of the investigation, heat sources like the sun, a stove, and a hot water bottle were addressed. The study took place before any didactic intervention at kindergarten had been undertaken. We were simply trying to capture the spontaneous everyday concepts of young children, considering the heterogenous development areas of a kindergarten cohort.

The result of this study shows that kindergarten children use the terms "warm" and "hot" to describe a higher water temperature. The synonymous use of these two terms has also been observed in other studies [26,29]. Thus, as in other studies, a distinction between warm and hot is not always made. However, this does not necessarily mean that kindergarten children generally are not capable of distinguishing between warm and hot, but perhaps that the situation did not call for it. In some interview situations, it became apparent that some children were able to express temperature gradations and could thus describe how something gradually became warmer or colder. In certain situations, they also used terms that expressed a temperature of medium degree.

In the present study, we often recorded statements such as "it gets hot", referring to heating vaguely as a process [2]. These results are not in line with Albert's research, who mentioned that children express such statements, not before the age of seven or eight. Moreover, expressions such as "you have to wait" indicate that some children have already developed an understanding that temperature changes do not happen from one moment to the next. According to Albert's research [26], children aged under seven years think that thermal changes happen immediately.

As in other studies [2,26], in our investigation, it became clear as well that almost no kindergarten child used the word "heat" in their spontaneous expressions. Their attempts at explaining were generally more descriptive and referred to what is directly experienced. Only sporadically, a child referred to a process that takes place invisibly, i.e. heat transfer, as well. Overall, we can say that questions asking for a prediction of thermal phenomena were easier than questions asking for an explanation. The children found a simple explanation, particularly in the tasks concerning the temperature of the water in the sun or under the tree, as well as when confronting the effect of a cold hot-water bottle. In contrast, it was very difficult for the kindergarten children to find an explanation why the stove warms the water, why a half-turned-up stove does not warm so much (or so fast), as well as why the hot water bottle becomes colder after a while. This may be due to the fact that in these cases, explanations require a conceptualization of heat, something that still seems difficult for kindergarten children to achieve.

The indirectly proportional task of this study, namely the heating of a small amount of water compared to the heating of a greater amount of water on a stove (at the same heating power), was particularly difficult for the kindergarten children. It was the question for which children were least often able to make a correct prediction. That this would be a difficult task is not surprising, given what we know already from previous studies [30]. However, it must be mentioned that there were also individual children who were able to make correct predictions or explanations of this phenomenon—this observation is not in accordance with the results of [30], who concluded that only children at the age of nine were able to give correct statements referring to indirect proportional tasks.

In contrast to former studies, this study focused only on children of kindergarten age. In this group, an age effect was found. Data show a tendency to a significant correlation between age and the interview performance, which indicates that older kindergarten children are generally better able to give correct predictions and explanations than younger ones. Nevertheless, this did not mean that younger children were not at all capable of giving the right answers to particular questions. Some of the younger children even achieved better interview performance than older children, which also highlights the performance heterogeneity in this age group. However, overall, it is clear that the ability to predict and explain thermal phenomena depends to a significant degree on children's age.

In addition to age, other developmental aspects such as exploratory behavior, task orientation, as well as interest in science, and language comprehension and their possible influence on interview performance were considered in this study. The results of the teacher ratings indicated that the investigated group of children is heterogeneous with regard to those different developmental areas. However, since these characteristics were often related with age (except for exploratory behavior), the influence of age had to be excluded first to elaborate on the role of these developmental areas. Therefore, partial correlations were studied, and it has become evident that science interest, in addition to language comprehension, had a significant influence on interview performance, while task orientation and exploratory behavior were not significant. Thus, the results of this study confirm the relationship between a strong interest in natural science and a better understanding of natural and technical phenomena. In the literature [43,44,63], it is well known that a person's interest plays a significant role in how much one turns to certain phenomena and engages with them. Accordingly, more knowledge and experience can build up in those areas of interest. Early science education should pick up on and promote interest in science but also promote concept creation because what is experienced must also be put into cognitive structures and expressed in words. Thus, the linguistic ability to communicate about simple thermal phenomena should also be promoted in class. This study showed clearly that kindergarten children with weaker language comprehension were not as capable of answering the interview questions about thermal phenomena as their peers having stronger linguistic abilities. This means that for some children, the experience and understanding of thermal phenomena may be greater than could be expressed in an interview.

All in all, it must be kept in mind that the study sample is composed of only 24 children. Thus, the results of this study must be considered as rather dependent upon the subjects in the sample. Therefore, generalizations of conclusions to the whole age cohort of kindergarten children should only be made very cautiously, if at all.

The knowledge gained here is of great importance for planning a suitable learning situation in kindergarten. Furthermore, it will allow us to assess the effect of the intervention we are designing for promoting the understanding of thermal phenomena in children. In a follow-up paper, we shall present a critical review of typical interpretations of children's understanding of thermal (and other physical) phenomena found in the tradition of science education and conceptual change research. This will be contrasted with a model of learning and understanding based upon an embodied/enactive approach that makes use of imaginative (in particular, narrative) forms of meaning-making interacting with direct physical experience.

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education sciences

Article

Preschool Children Science Mental Representations: The Sound in Space

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Abstract: The aim of the current study was to examine the way in which preschool children deal with the concept of sound. For this purpose, a study was carried out in the context of detecting and categorizing the mental representations among young children of sounds which propagate through space from source to the receiver. Specifically, 91 preschool children aged 5–6 years voluntarily participated in individual semi-structured interviews which were carried out by three researchers in a special area of kindergartens. During these interviews, the children were asked to express their views on the three following axes: the concept of sound itself; the subjective characteristics of sound; and the phenomenon of the production and propagation of sound. The results of the research showed that while a small percentage of children recognized the propagation of sound in space, the vast majority of them associated sound with either the object that produced it or with the object that received it.

Keywords: genetic epistemology; mental representations; preschool children; physical sciences; sound

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1. Introduction

The initiation of children aged 4–8 years into the world of Physical Sciences has been a growing interdisciplinary issue for education and research in recent decades. In a series of studies and teaching proposals that move toward diverse theoretical directions [1,2], a number of initiatives have been developed which over time have influenced international curricula and teaching strategies, and at the same time have contributed to the development of specific research and educational communities and traditions now recognized as Early Childhood Science Education. Along one of these directions, research orientations are placed within the broader context of Social Constructivism and Science Education, setting the study of young children's mental representations of concepts and phenomena of Physical Sciences in the core of the research process [3–5]. Within this framework exists the present study which investigated the mental representations of children for the propagation of sound in space.

2. Theoretical Background and Literature Review

2.1. The Issue of Sound Comprehension

The issue of a sound approach in education constitutes a systematic dimension of the curricula of Physics. Sound—both as a concept that developed through the history of human thought and as a fundamental term in science and education—has multiple scientific, cognitive and semiotic meanings [6]. Different disciplines investigate sound through different approaches and methodologies. In experimental psychology, research has shown that audio information can support visual information by creating a multimodal combined perception [7]. Auditory modalities improve the transfer of spatial information and spatial orientation performance and have a positive impact on the memory of spatial objects in a visual environment [8]. For example, in cartography, the auditory information of a property of an object in a map help memory in determining the location of the object. The integrated audiovisual information for the semantic property of a spatial object creates a binding between the object–identity and the object–location, which has an effect in memory process [9]. Although research in experimental psychology explores cognitive processes related to the connections between sound information and spatial entities as referring to the environment, the present study adopts the science education approach. According to physics, sound is an oscillation of molecules of an elastic medium (e.g., air) which, however, do not move from the source to the receiver. The source mechanically stimulates its neighboring molecules, which in turn stimulate those next to them, etc., resulting in a wave which finally stimulates the receiver's sensory organ. Physics deals with the construction of scientific/conceptual models that explore and describe this mechanism, while medicine, biology and neuroscience deal with the way the aforementioned mechanical stimulus which reaches the receiver in the form of a wave is encoded in terms of biological, cognitive processes, etc. Science education, among other things, deals with the possibility of a conceptual approach to these scientific models by students. From this perspective, the current study confines its interest in the way students think about sound.

Particularly in the education context, the basic characteristics of sound production and propagation have been approached in the earlier stages of curriculums that gradually lead to the conceptualization of sound as a wave phenomenon in the later stages. Students seem to encounter difficulties when they deal with specific aspects of sound, such as the way it is produced and it propagates through air, as well as its nature in general [10]. More specifically, they tend to attribute material properties to sound, advocating that since a 'solid' object cannot go through another one, it is impossible for sound to move across solids [11]. In addition, students often connect sound with its source, without making any reference to wave propagation [12]. Regarding sound production, students seem to focus on the context where it is generated [13]. The following common misconceptions are in line with this views that 'sounds can be produced without using any material objects', 'hitting an object harder changes the pitch of the sound produced', 'sounds can travel through empty space (a vacuum)', 'sounds cannot travel through liquids and solids', 'when waves interact with a solid surface, the waves are destroyed', etc. [14].

The materialistic nature of sound in students' thinking was studied by Eshach and Schwartz [15]. In particular, the researchers used the so-called 'substance schema' framework [16] in order to determine the extent to which eighth grade students attribute a range of material properties to sound (materialization of sound). Their results clearly showed that students tend to attribute pushable, frictional, containable and transitional features and properties to sound. All these are well reflected in the following students' statements: 'sound is pushed by the air, water, a barrier, is attracted by a stethoscope, or hits the walls'; 'sound experiences drag when it propagates through water'; 'sound (voice) is contained in bubbles'; and 'sound moves in straight, spiral or in a form of crescent shaped lines' [15] (pp. 746–753). Another finding of the Eshach and Schwartz [15] study suggested that students' thinking is governed by the view that the medium plays a key role in the propagation mechanism of sound. Along this line, students hold the view that sound tends to reformulate as it travels along diverse mediums.

Lautrey and Mazens [11] pointed out three naïve theories, comprising five mental models that encapsulate the substantial nature of sound. Regarding the first naïve theory, students exclusively attribute material substances to sound. Here, students claim that sound cannot move across solids as they are asked the question of how they are able to hear a sound that propagates through a material (model 1). Even in the case that they come across everyday life situations which disclose contradictory data, they tend to insist in their initial view. An exemplar paradigm of that is that they either refer to holes (model 2) or they perceive sound as a harder substance that the solid that can penetrate a wall (model 3) in order to explain the way they can hear noise from outside when they are in a closed room. According to the second naïve theory, students deal with sound as a substance, however, without attributing any kind of material properties to it. According to their view, sound can be invisible or transparent as a ghost or smoke (model 4). Finally, according to the third naïve theory, sound is regarded in a transmission context by adjacency where terms such as 'vibrating' or 'resonating' are used to describe its propagation mechanism. In line with this view are the findings of Hrepic, Zollman and Rebello [17], who demonstrated two main mental models: the wave model and entity model, as well as combinations of these. In particular, the wave model refers to sound as a vibration within a material medium which acts as a prerequisite for its propagation. The medium is made up of particles that oscillate around an equilibrium position. It is this oscillation that represents sound. On the other hand, according to the entity model, sound is an autonomous material entity that differs from the medium through which it propagates, which in turn becomes unnecessary in its propagation process. Thus, sound can propagate through empty space that exists between the particles of the medium, irrespectively of whether it affects them or not. In both cases, the propagation of sound is independent of the kinetic state of the particles that constitute the elastic medium.

2.2. Sound Approach within Early Childhood Science Education

At the pre-school level, the focus is both on the first organized sound experiences and the production and distinction of sounds as well as the initiation of children into musical sound. For example, during teaching activities, children classify, by association, sounds produced by various objects [18], while in other cases, they use the timbre (overtones) as a criterion for classifying the differences in materials, e.g., metallic sound for metals [19]. In addition, quite common is the usage of sounds as modalities, which along with oral speech and spatial entities compose narrative environments in the physical and/or digital space [20].

While for older children the main research issues seems to deal with the nature of sound, its wave character or its propagation through air and other materials [21,22], for younger children the most important issue has to do with the recognition of sound propagation in space. This difficulty constitutes a fundamental parameter for both the creation of learning and teaching activities as well as the orientation of relevant research, as it seems it goes beyond a simple mental representation and forms a prelogical feature of children's thinking, which requires systematic treatment. This aspect has been the subject of systematic research in the context of Genetic Epistemology. In a series of relevant studies, the hypothesis that was studied was whether children aged 7–8 years are able to conceptualize the propagation of non-tangible physical entities in space such as heat, light or sound [23,24]. This is due to the absence of a logical tool, operational transitivity, which allows the natural transition of such an entity between source and receiver to be understood as a two-step process: source → space and space → receiver. Children's thinking remains trapped in a direct source → receiver transition pattern and thus they do not attribute sound to its propagation any of its distinct characteristics [25,26]. Regarding the propagation of sound, for example, from one percussion supported in one box to another percussion, research has shown that '... Up to 7 years of age we only find ... immediate transmissions at a distance ... ...: one diapason acts directly on the other because they are close (without touching each other) or similar, and without the box, the table or the air playing any role' [27] (pp. 214–215).

This structural barrier of children's thinking has been traced in a few studies of different theoretical orientation that have also tried to examine the way children 4–7 years old conceptualize sound. In most of these cases, young children associated sound with their own actions as well as with objects that produce sounds [12], while they considered that sound has the properties of a material object [13]. In accordance with the substantial entity of sounds are the findings of Gallegos-Cázares et al. [28]. In particular, the researchers studied the propagation of sound with 18 preschool children aged 4–5 years old and found that children of this age deal with sound as a material entity that requires space to propagate in order to be listened. Therefore, for example, when one speaks via a hose telephone, sound passes through the tiny hole and is received by the other's ear. Nevertheless, in the case in which the hole is folded and squeezed, sound gets stuck in it and cannot pass through. As a result, it cannot be heard. In this line of thought, if someone were to wear earmuffs, they could not listen as the substantial entity of sound cannot pass through the plastic material. Quite interesting is the fact that many children tried to attribute porosity (little holes) to that plastic material in order to match their premise with the fact that someone in reality can listen to a loud sound even when they wear earmuffs.

Kalogiannakis, Rekoumi and Chatzipapas [29], studied the mental representations of 4–6 year-old children and found that they were able to recognize the loudness and timbre of sounds, however, they showed greater difficulty with respect to the sounds of mechanical and musical instruments. They were also able to recognize the sounds that they had heard and were capable of matching the sounds to the corresponding images. From a perspective of the didactic treatment of relevant research findings, the authors proposed a series of didactic activities in the context of curriculum implementation. In this line, Smith and Trundle [30] proposed a 'sound study' unit that spans approximately one month and aspires to engage young children with the properties of sound through life, Earth and Physical Sciences. In particular, children have the opportunity via this unit to hear, see and feel sound through distinct activities. Therefore, for example, children experience a listening walk in the classroom, in the hallway and outside where they can hear different kinds of sounds. In addition, they visualize sound through the observation of a vibrating tuning fork, and they feel sound by placing their hands on their own throat while making various sounds (sing, talk, whisper, whistle). All these activities capitalize on children's interest and set the conditions for them to conceptualize sound in a way compatible with school-level Physics.

In the context of the Cultural–Historical Theory of Activity, having completed a preschool teacher training course, specific activities were developed with body sounds, sounds of familiar materials and objects of everyday life as well as the propagation of sound through various materials [31]. This research highlights the importance of a designed communication framework as well as the interactions and adherence to rules. Here, analysis is mainly focused in this direction and less on learning outcomes, which nevertheless seem satisfactory.

Research evidence through systematic interaction with 4–6-year-old children [32] showed the way that teachers, through a combination of play and learning, contribute to children's emerging scientific knowledge, which in turn enhances children's conceptual awareness about sound. Children interact with each other, as well as with their teacher by linking the contextual elements of the learning environment with a conceptual focus and understandings leading to the emergence of knowledge that sound is actually vibrations in a medium. Furthermore, acting in this way, their teachers contribute to bridge children's daily mental representations with the scientifically accepted concepts.

Christidou et al. [3] investigated 4.5–5.5 year-old children's noise awareness by recording ideas that referred to the conceptualization of noise, noise annoyance, health effects and protection measures. Regarding the conceptualization of noise, children define noise as annoyance, based on loudness, or identify it through examples. As for the source of noise, children display perceptions that attribute noise production to a human-made environment, natural environment, traffic, or work environment. Children's responses are also categorized in terms of subjectivity, as the same sound may be annoying to some children but not to others. In addition, it has been shown that activities based on socio–cognitive and multimodal teaching and learning processes can improve children's noise awareness to some extent.

Finally, in another study, representations of children aged 4–5 years about sound production, perception and propagation were diligently studied within the framework of embodied cognition [33]. The categorization of the research data revealed three levels of representations. In the first level, the sound is associated with the objects, while in the second, the sound is associated with the relation of objects to their environment, attributing to it some distinct, elementary features. In the third level, sound appears to have some inherent characteristics that increase its possibilities of interacting with objects and subjects of the environment. It seems that 'sound starts from perceptual elements and is linked to actions, although its complexity also shows that they incorporate characteristics that go beyond this corporal correlate' [33] (p. 952).

In the current research, an attempt was made to record mental representations of 5–6-year-old children about the recognition and propagation of sound in space, as well as about some basic features that characterize sound. The specific orientation of the research does not only lead to the recording of children's' representations, but also to a kind of classification which draws from the concept of operational transitivity.

Given that previous research has shown that children aged 5–6 years have the ability to express mental representations for non-tangible physical entities in space, before and/or after a teaching intervention, it seems that we can assume that children would also have the same cognitive ability for sound. Thus, the following three research questions (RQ) were posed:

(RQ1) How and to what extent do children identify sound as a physical entity as it appears in the context of everyday life.

(RQ2) How and to what extent do children differentiate sounds based on its subjective characteristics.

(RQ3) How and to what extent do children state that sound is produced and propagated as a distinct physical entity?

3. Materials and Methods

In the present study, a qualitative research approach was adopted [34].

3.1. Participants

This study involved 91 children from 5 years and 3 months to 6 years and 3 months (47 girls and 44 boys, average age: 5 years and 8 months) who attended 7 kindergarten classes in an urban area of Patras (Greece). These children, who volunteered to 'play' with the researchers, had no experience of organized sound activities in their classrooms. All socio–economic levels (low, middle, and high) were equally represented in the sample.

3.2. The Procedure and the Interview

The research was conducted through individual semi-structured interviews which took place in specially designed areas of kindergartens. The interviews lasted 12–17 min and were recorded, while at the same time protocols of non-verbal behaviors were observed. The Ethics Committee of the Department of Educational Sciences and Early Childhood Education of the University of Patras approved the study and consent procedures (the approval No: 12/8.3.2019).

The interview included tasks that covered all three research questions. Regarding the first research question, the mental representations of children about sound in everyday life (natural and artificial sounds, music) were investigated. With regard to the second research question, the issue of sound discrimination based on certain characteristics was investigated, while for the third research question, the effort was focused on establishing the recognition of the sound produced in a source and its propagation to the receiver. Regarding the third RQ, in task 3.3, the researchers decided to embed animated characters on Figure 1, so that children felt comfortable and happy. The usage of fictional characters did not affect the research results, as no kind of feature related to an imaginary world appeared in any of students' ideas. The aforementioned point had been also confirmed by an earlier pilot test for this image. In addition, the use of image (Figure 1) may have limited the expression of children's ideas, because it is a two-dimensional representation, as opposed to the fact that sound is evenly distributed throughout the three-dimensional space. This is a limitation of the research, which can be customized by designing data collection scenarios with 3D entities.

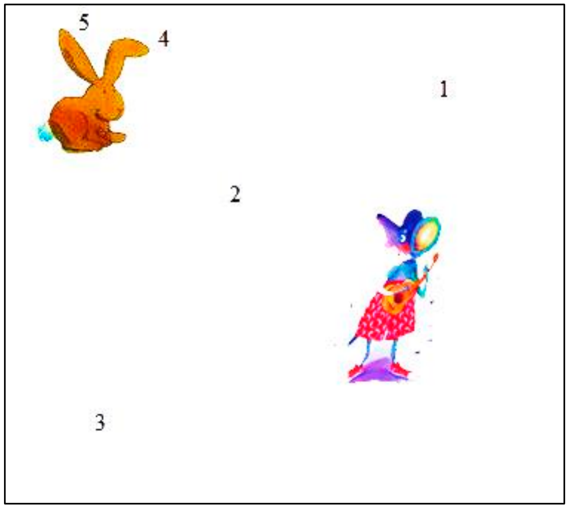

Figure 1. Which points does the singer's voice reach?

The interview questions and the order in which they were asked are presented in Appendix A (Table A1).

3.3. Data Analysis

Data analysis was based upon transcribed data of the discussions between children, the researcher and the individual observation protocols. The data were encoded and organized into 'categories'. Categories were derived in advance based on the ability of children to use transitional reasonings about sound and were modified by reference to the empirical data, i.e., whether they recognized that sound is propagated in space. As Cohen, Manion and Morrison [35] (p. 476) suggest 'content analysis involves coding, categorizing (creating meaningful categories into which the units of analysis—words, phrases, sentences etc.—can be placed), comparing (categories and making links between them), and concluding'.

Throughout interview questions, three levels of answers were distinguished that correspond to particular mental representations. At level a (sufficient answers), answers were classified in which the propagation of sound in space was fully recognized along with its own properties. At level b (intermediate answers), answers were classified in which children's reasoning was dominated by both the sources and the receivers while the direct transition of sound between them was often recognized. At level c (insufficient answers), answers were classified in which the children's thinking was strongly tied to the voice as well as to the sources and receivers of sounds. The analysis and categorization of responses was performed by two independent researchers. The agreement among the two researchers was higher than 95%.

4. Results

In what follows, the data of the interviews and children's performance to all tasks regarding the three research questions are presented. In particular, children's mental representations were categorized for each task and representative children's statements as well as frequencies and related frequencies of their answers are given below.

4.1. First Research Question

Task 1.1. What is sound?

Regarding this question, three different types of mental representations were recorded, which stem from a spectrum of answers on one end of which lie the recognition of sound and on the other its direct connection with human voice.

a. *Sound propagates in space*. Here, children seemed to recognize that sound acts independently from both its point of production and the receiver. To quote pupil 6 (P. 6), 'It's something that reaches our ears . . . . it comes from around' (Researcher. 'Why do you think this? How do you think it?'), 'Because we keep hearing it wherever we go . . . '.

b. *Sound as a product of human and social activity*. Answers in this category were focused on the source of the sound production. For example, P. 17. 'When we hit something . . . . or on the roads from the cars . . . '.

c. *Sound as a product of vocal expression*. This category included answers that recognize an unambiguous relationship between sound and voice. While in some cases other types of sounds were mentioned, the main emphasis on sound production here remains voice. For example, P. 43. 'If we shout, the sound is generated', (R. 'Is there any other way for a sound to be produced?') 'With voices . . . from mouths . . . ', (R. 'Only human can produce sound?), 'Yes, humans . . . and animals that bark let say . . . '.

Table 1 presents the frequencies of children's responses to task 1.1.

Table 1. Children's responses to task 'what is sound?'.

Categories of Responses	Frequencies	Relative Frequencies (%)
a. Sound propagates in space	13	14.3
b. Sound as a product of human and social activity	61	67
c. Sound as a product of vocal expression	17	18.7

Task 1.2. Could you tell me some kind of sounds that you know?

Children's answers to this question hold the same basic characteristics with those of task 1.1. Here, as well the way children express their views, the direction of their thinking is presented. Thus, from the analysis of their responses, the following three levels of answers were distinguished.

a. *Sound propagates in space*. Here, children seemed to attribute to sound the capability of propagation in space. For example, P. 33. 'The sound that comes out when a hammer strikes', (R. 'When you say 'it comes out' what do you mean?'), 'I mean that as the hammer strikes its target, a loud sound generates reaches our ears'.

b. *Sounds as a product of human and social activity*. In these answers, children focused their thinking on the actions that are capable of sound production. For example, P. 2. 'When two things strike, we hear the blow', (R. 'How do you think that? Could you give me an example?'), 'Yes . . . when we clap . . . our hands click . . . '.

c. *Sounds attributed exclusively to voices*. Here, children seemed to limit their views about sound exclusively on voices. For example, P. 21. 'The voices of children at school', (R. 'Could you give me any other example?'), 'Yes, voices at home . . . . or on the road'.

Table 2 presents the frequencies of children's responses to task 1.2.

Table 2. Children's responses to task 'Could you tell me some kind of sounds that you know?'.

Categories of Responses.	Frequencies	Relative Frequencies (%)
a. Sound propagates in space	16	17.6
b. Sound as a product of human and social activity	66	72.5
c. Sound as a product of vocal expression	9	9.9

Task 1.3. Is music a kind of sound?

Children were prompted to listen to an audio excerpt from an orchestral melody for a few minutes. They were then asked to answer the question of whether 'music is sound'. The researchers' goal here was to investigate whether children associated music, which is a particular cultural element, with other everyday sounds. From data analysis, the responses were classified into three distinct levels.

a. *Music is sound*. This category included answers that referred to the existence of music everywhere in space. For example, (R. 'Do you think that the music we listen is sound?') P. 64. 'Yes, it is . . . but it does not look like other sounds . . . it is somewhat special . . . ', (R. 'So what is special about it?'), 'It is produced from instruments that play all together . . . and individually sometimes'.
b. *Music is associated with sound, in an unstable manner yet*. In particular, when children focused their attention on sound perception, they did not seem to distinguish sound from music. However, when they referred to the sources of production, they seemed to recognize sound and music as different entities. For example, P. 60 'We hear both (music and sound) . . . with our ears . . . music is like sound. That is, it is like the sound we hear . . . But they are made up differently . . . ', (R. 'What do you mean they are 'made up' differently?'), 'Let's say . . . the music from guitars and the sound from our voices ...'.
c. *Music and sound totally differ*. These answers record a clear distinction between 'sound' and 'music', i.e., music was understood as an element that was not related to sounds. For example, P. 51 'Music is 'music', it is not sound', (R. 'So, do they differ somewhere? What is different about them?'), 'Yes, of course. The music is songs . . . That is, it is not done by . . . when a voice is heard . . . '.

Table 3 presents the frequencies of children's responses to task 1.3.

Table 3. Responses to task 'Is music a kind of sound?'.

Categories of Responses	Frequencies	Relative Frequencies (%)
a. Music is sound	18	19.8
b. Music is associated with sound, in an unstable manner yet.	56	61.5
c. Music and sound totally differ	17	18.7

4.2. Second Research Question

Task 2.1. Are all sounds the same? If not, where do they differ?

This question formed the initial basis for the development of dialogues in order to identify the subjective characteristics of sound that are important for young children. The following three categories of responses emerged in these discussions.

a. *Answers in which differences are mainly identified on the different subjective characteristics of sound*. Here, children's responses are mainly related to loudness and timbre while the distinction of sounds seems to be a constant element of their reasoning. For example, P. 46. 'They are not all the same. Others are strong and conflict pain to our ears, and other . . . we do not even listen to them . . . . or let's say if we are far away we do not hear well when someone speaks', (R. 'Could we distinguish people who speak the same loud?'), 'Do you mean to distinguish who is it? Who is talking?' (R. 'Exactly to distinguish who speaks when two people speak the same loud'). 'Yes, it is quite easy . . . my mom has a totally different voice from my sister Joana'.

b. *Answers that recognize limited differences in sounds*. This category included children's responses that pointed out differences between sounds in an instable and/or difficult manner. For example, P. 11. 'Hmmm . . . it seems to me that they are not the same . . . that is . . . I do not know', (R. 'Do you want to explain it further? What do you think about these sounds that are not the same?'), 'I think they are the same but sometimes they do not look alike . . . they differ', (R. 'Could you just tell me two of these sounds to make it clearer?'), 'The loud and the quiet sound'.

c. *Answers in which no criteria were found for sound discrimination*. Few children were not able to use criteria for sound discrimination. From the relevant discussions, it seemed that although these children recognized differences between sounds, they were not able to find indicators of sound discrimination. For example, P. 3 'They are the same . . . they do not change . . . ', (R. 'I mean if we hear two different sounds are they the same?'), 'They are the same', (R. 'So, does that mean that the voice of your mother and the sound that comes from TV are the same?) 'No, it's a totally different thing my mother voice and the sound from TV . . . nevertheless, the sound does not change'.

Table 4 presents the frequencies of children's responses to task 2.1.

Table 4. Responses to task 'Are all sounds the same? If not, where do they differ?'.

Categories of Responses	Frequencies	Relative Frequencies (%)
a. Differences based on subjective characteristics of sound	24	26.4
b. Recognition of limited subjective characteristics of sound	53	58.2
c. Absence of criteria for sound discrimination	14	15.4

Task 2.2. Behind you there are some objects made of iron, wood and glass. I am going to hit two of them and I would like you to guess which one I am hitting each time. For example, if I hit these two objects made of plastic, they make that sound. Let us see if we can recognize the sounds without observing the objects that being hit.

With this task, an attempt was made to approach the familiarity of children with the timbre of sounds produced from ordinary everyday materials. At this stage, we did not use sounds such as the voices of children's parents, as the strong social marking creates an experiential relationship with the timbre of these sounds that goes far beyond the physical characteristics of the sound. In this task, we generated six sound stimuli by hitting two metal knives, two wooden spoons and two glass bottles in succession. Later, the stimuli were generated through hitting a metal with a wooden object, a wooden with a glass object and a glass object with a metal object.

The categorization of children's responses was based on whether the origin of the sound was recognized or not. For example, P. 77 'It's the irons', P.41 'The iron hit the wood', P. 1 'It's probably the knives' (two glass bottles collide with each other). It should be noted that sounds produced by objects of the same material were much more recognizable than those produced by objects of different materials. Moreover, children who failed to distinguish sounds often gave their response instantly. By so doing, instead of disclosing their failure, they gave the wrong impression that they did not realize that a kind of discrimination was possible. Thus, regarding the recognition of ordinary everyday sounds, children were classified into the following three categories:

a. Those that satisfactorily recognized 5–6 sounds;
b. Those that satisfactorily recognized 3–4 sounds;
c. Those that either satisfactorily recognized 1–2 sounds or do not answer at all.

Table 5 presents frequencies of children's responses to task 2.2.

Table 5. Responses to task related to the recognition of sounds that come from everyday materials.

Categories of Responses	Frequencies	Relative Frequencies (%)
a. Recognition of 5–6 sounds	13	14.3
b. Recognition of 3–4 sounds	38	41.7
c. Recognition of 1–2 sounds	40	44.0

4.3. Third Research Question

Task 3.1. How are sounds produced, how are they made of?

With this question, an attempt was made to determine the way in which children approach the production of sound and especially whether they satisfactorily distinguish the concept of sound from the objects or the process of its production. As children do different centrations on sound creation, their answers fell into three distinct categories.

a. *Answers in which sound is recognized as something that can be produced by any source*. This category includes responses that refer to different audio sources, often without any kind of distinction between them. Essentially, the emphasis here is on the 'sound' itself. For example, P. 14. 'Sounds are produce all the time . . . in many ways . . . through voices, through objects . . . the music, the cars . . . ', (R. 'How can a sound be produced?'), 'Hmmm . . . the objects have to hit each other to get out sound . . . ' (R. 'How about cars, how does the sound come out?'), 'Hmmm . . . the engine knocks . . . even from the exhaust . . . something hits there too . . . and as the sound comes out we hear it'.
b. *Answers in which limited natural and artificial sound sources are recognized while the distinction between objects of sound production and sound itself is blurred.* Here, we have children's answers which refer to a limited number of audio sources and face difficulties in identifying different sources. For example, P. 28. 'Hmmm . . . people's voices . . . ', (R. 'Any other way?'), 'animals voices', (R. 'except of voices, is there any other way to produce a sound?'), 'hmmm . . . . how else?', (R. 'I mean only from voices can produced sounds?'), 'Not only . . . ', (R. 'Could you please express your thoughts?')?, 'hmmm . . . let's say when a car passes . . . ', (R. 'In any other way?').
c. *Answers that focus exclusively on one type of voice source.* In this category of responses, children focused on a single-signal type of sound source and mainly on the human voice. For example, P. 21. 'From the voices we make', (R. 'In any other way?'), 'When we talk . . . when we cough . . . ', (R. 'Do you think of anything else . . . of any other way that sounds can be produced?'), 'Oh yes, animals can also produce sounds', (R. 'How are they produced?'), ' . . . as the bark . . . !'.

Table 6 presents frequencies of children's responses to task 3.1.

Task 3.2. Where do the sounds go? If we produce a sound here on the table, inside the room, will it go somewhere else?

The answers to this question reflect the different mental representations that children use in order to approach the concept of sound. Having analyzed the data, the responses were classified into three distinct categories.

Table 6. Responses to task 'How are sounds produced, how are they made of?'.

Categories of Responses.	Frequencies	Relative Frequencies (%)
a. Sound produced from a variety of sources with a clear distinction between sound and sources	11	12.1
b. Sound production from a limited number of sources without a clear distinction between sound and sources	61	67
c. Correlation of sound mainly with voice	19	20.9

a. *Answers where children recognize that sound is propagated everywhere in space.* This category of responses is quite interesting as it highlights the ability of young children to recognize sound in space. For example, P. 39. 'Everywhere . . . all around . . . ', (R. 'How do you know that?'), 'Because, let's say, in case the bell of Saint Andreas rings, it can be also heard by us that we live by the sea . . . . All the neighbors can hear it . . . . It's like flying everywhere', and P. 64. 'Everywhere . . . when it comes out of the CD let's say . . . it goes everywhere. Everywhere . . . like in concerts that everyone is able to listen to the music, irrespectively of the place it sits . . . '.

b. *Answers where sound is closely related to the way that is received by humans.* In these responses, the receiver seems to hold a particularly important position, which leads to a kind of decentralization of children's thinking from the sources of sound production. For example, P. 10. 'In our ear', (R. 'How does this happen?'), 'It happens . . . because we hear it . . . ' and P. 88. 'Everywhere', (R. 'If we produce a sound here on the table, inside the room, will it go somewhere else?'), 'It will go around here', (R. 'Could you show me the exact point it will go?'), 'Yes . . . here where we are sitting . . . '.

c. *Answers that focus on sound production*. In these responses, the main focus stands on sound sources. For example, P. 30. 'They do not go anywhere . . . ', (R. 'Could you explain it further to me?'), 'They are people's voices . . . they do not go somewhere . . . they just go along with peoples . . . '.

Table 7 presents frequencies of children's responses to task 3.2.

Table 7. Responses to task 'Where does sound go?'.

Categories of Responses	Frequencies	Relative Frequencies (%)
a. Sound is propagated everywhere in space	14	15.4
b. Focus on the perception of sound by humans	62	68.1
c. Focus on sound production	15	16.5

Task 3.3. Here, we can see a mouse who sings and a rabbit who wants to hear her songs. I will show you some points to tell me whether her voice could be heard there.

With this question, the children had the opportunity to choose points in space independently of the hypothetical listener. Therefore, by using this illustration, we sought to understand whether children are able to recognize the sound regardless of the source and the receiver.

Children's responses were classified into three distinct categories.

a. *Answers where children recognize the propagation of sound throughout space.* In this category of responses, all five points were selected without any special distinction. For example, P. 77. 'In all places . . . here . . . there . . . everywhere', (R. 'How do you know that?'), 'Hmmm . . . wherever we go we will listen'.

b. *Answers where sound is linked with an imaginary space defined by the linear source-receiver relationship*. In these responses, the presence of sound was recognized in points 2, 4 and 5. For example, P. 10. 'There . . . in the ears of the rabbit the song will be heard' and P. 70 (R. 'Somewhere else?'), 'Maybe here too (point 2) . . . I guess . . . ' (R. 'Why? How do you think this?'), 'Because if rabbit's ear placed there, I think it will be able to hear . . . '.

c. *Answers focused solely on the sound receiver*. Some children's responses seem to focus solely on the sound receiver. For example, P. 52. 'In rabbit's place where he is able to hear . . . here and there (points 4 and 5)' (R. 'Could you tell me how you think this?'), 'Hmmm . . . it will be where he can hear . . . that is in his ears'.

Table 8 presents frequencies of children's responses to task 3.3.

Table 8. Responses to task 'Where do the sounds go?

Categories of Responses	Frequencies	Relative Frequencies %
Sound propagates everywhere	17	18.7
Sound between the source and the receiver	60	65.9
Sound on the receiver	14	15.4

Table 9 presents the frequency of children's responses at each stage of the process, and the exact sequence of responses that each child provided during the interview.

Table 9. Frequencies (f) of pupils' representations (n = 91).

	Answers	a. Sufficient	f	b. Intermediate	f	c. Insufficient	f
First Research Question	Question 1.1. What is sound?	5, 6, 14, 15, 31, 33, 42, 46, 61, 69, 77, 84, 91	13	2, 3, 4, 9, 10, 11, 12, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 29, 32, 34, 35, 37, 39, 40, 41, 44, 45, 47, 49, 50, 51, 52, 54, 55, 56, 57, 58, 59, 60, 63, 64, 65, 66, 67, 68, 70, 72, 73, 74, 76, 78, 79, 80, 81, 82, 83, 85, 87, 88, 90	61	1, 7, 8, 13, 21, 28, 30, 36, 38, 43, 48, 53, 62, 71, 75, 86, 89	17
	Question 1.2. Sound that are recognized by children.	5, 6, 12, 14, 15, 31, 33, 42, 46, 60, 61, 69, 77, 84, 90, 91	16	2, 3, 4, 8, 9, 10, 11, 13, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 32, 34, 35, 36, 37, 38, 39, 40, 41, 44, 45, 47, 49, 50, 51, 52, 54, 55, 56, 57, 58, 59, 62, 63, 64, 65, 66, 67, 68, 70, 72, 73, 74, 75, 76, 78, 79, 80, 81, 82, 83, 85, 87, 88, 89	66	1, 7, 21, 30, 43, 48, 53, 71, 86	9
	Question 1.3. Is music a kind of sound?	5, 6, 12, 14, 15, 26, 31, 33, 42, 46, 55, 61, 64, 69, 77, 84, 90, 91	18	2, 3, 4, 8, 9, 10, 11, 16, 17, 18, 19, 21, 22, 23, 24, 25, 27, 29, 32, 34, 35, 37, 39, 40, 41, 44, 45, 47, 49, 50, 52, 54, 56, 57, 58, 59, 60, 63, 65, 66, 67, 68, 70, 72, 73, 74, 76, 78, 79, 80, 81, 82, 83, 85, 87, 88	56	1, 7, 13, 20, 28, 30, 36, 38, 43, 48, 51, 53, 62, 71, 75, 86, 89	17
Second Research Question	Question 2.1. Are all the sounds the same?	2, 5, 6, 12, 14, 15, 22, 26, 31, 33, 40, 42, 46, 55, 58, 60, 61, 65, 69, 73, 77, 84, 90, 91	24	4, 8, 9, 10, 11, 13, 16, 17, 18, 19, 20, 21, 23, 24, 25, 27, 29, 32, 34, 35, 36, 37, 39, 41, 44, 45, 47, 49, 50, 51, 52, 54, 56, 57, 59, 63, 64, 66, 67, 68, 70, 72, 74, 76, 78, 79, 80, 81, 82, 83, 85, 87, 88	53	1, 3, 7, 28, 30, 38, 43, 48, 53, 62, 71, 75, 86, 89	14
	Question 2.2. Sound recognition.	6, 14, 15, 31, 41, 42, 46, 61, 64, 69, 77, 84, 91	13	2, 3, 4, 5, 8, 9, 10, 11, 12, 17, 19, 21, 22, 24, 26, 27, 28, 32, 33, 34, 35, 37, 39, 44, 47, 49, 54, 55, 58, 60, 65, 66, 73, 81, 82, 85, 89, 90	38	1, 7, 13, 16, 18, 20, 23, 25, 29, 30, 36, 38, 40, 43, 45, 48, 50, 51, 52, 53, 56, 57, 59, 62, 63, 67, 68, 70, 71, 72, 74, 75, 76, 78, 79, 80, 83, 86, 87, 88	40

Table 9. *Cont.*

	Answers	a. Sufficient	f	b. Intermediate	f	c. Insufficient	f
Third Research Question	Question 3.1. How are sounds produced?	6, 14, 15, 31, 42, 46, 61, 69, 77, 84, 91	11	5, 3, 4, 8, 9, 10, 11, 12, 16, 17, 18, 19, 22, 23, 24, 25, 26, 27, 29, 32, 33, 34, 35, 37, 39, 41, 44, 45, 47, 49, 50, 51, 52, 54, 55, 56, 57, 58, 59, 60, 62, 64, 65, 66, 67, 68, 70, 72, 73, 74, 76, 78, 79, 80, 81, 82, 83, 85, 87, 88, 90	61	1, 2, 7, 13, 20, 21, 28, 30, 36, 38, 40, 43, 48, 53, 63, 71, 75, 86, 89	19
	Question 3.2. Where do sounds go?	5, 6, 14, 15, 31, 39, 42, 46, 61, 64, 69, 77, 84, 91	14	2, 3, 4, 8, 9, 10, 11, 12, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 32, 33, 34, 35, 37, 40, 41, 44, 45, 47, 49, 50, 51, 52, 54, 55, 56, 57, 59, 60, 63, 65, 66, 67, 68, 70, 72, 73, 74, 76, 78, 79, 80, 81, 82, 83, 85, 87, 88, 90	62	1, 7, 13, 30, 36, 38, 43, 48, 53, 58, 62, 71, 75, 86, 89	15
	Question 3.3. Sound in space.	5, 6, 12, 14, 15, 31, 33, 42, 46, 55, 61, 64, 69, 77, 84, 90, 91	17	2, 4, 8, 9, 10, 11, 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 32, 34, 35, 36, 37, 38, 39, 40, 41, 44, 45, 47, 49, 50, 51, 54, 56, 57, 59, 60, 63, 65, 66, 67, 68, 70, 72, 73, 74, 76, 78, 79, 80, 81, 82, 83, 85, 87, 88, 89	60	1, 3, 7, 28, 30, 43, 48, 52, 53, 58, 62, 71, 75, 86	14

5. Discussion

In the present study, mental representations of sound among 5–6-year-old children were studied. The focus of the study was not to record children's reflections on certain characteristics of sound such as noise [3], neither their aptitude of identifying everyday sounds and sound sources [31]. Instead, an attempt was made to explore children's ability on sound recognition in space. This choice is based on the interpretation given by Genetic Epistemology for the understanding of non-tangible concepts [23,24,26,27] and is of double importance for the learning processes of young children. On the one hand, the determination of the approach of sound through mental representations that allow the transitional reasoning of two steps points out the possibility of young children to approach the existence of sound in space. On the other hand, this finding shows the direction in which teaching activities should be developed for children who do not adopt transitional reasonings. The findings of the present study indicate that preschool children are able to conceptualize to some extent that sound spreads everywhere in space and propagates from the source to the receiver. Undoubtedly, the form that sounds obtains through this propagation may be interpreted by the 'wave' and 'entity model' found by Hrepic, Zollman and Rebello [17]. Indeed, these models could be implied in children's responses regarding our three research questions. Nevertheless, as our study focused on 5–6-year-old pupils, in contrast to the sample studied by Hrepic et al. [17] which consisted of university students, we decided not to deal with the appearance of these models in our children's thinking.

In the three tasks of the first RQ, it seemed that 14–20% of students recognized sound independently of its sources of production, its origin, or particular forms that manifest itself such as musical sound. The conceptualization of sound as a distinct physical entity is a finding of relevant research that has focused on this issue [28,33]. However, the vast majority of children (61.5–72%) refer to sound in close relation to the sources of production and the activities that produce distinct sounds, as well as to human hearing. This finding is consistent with similar studies that show the key role that the sources of sound play in the thinking of children aged 5–7 years [12,29,31]. Undoubtedly, the basic children's reasoning regarding the propagation of sound lies on the immediate transmission of an instantaneous stimulus. In addition, there is another group of children who seem to associate sound exclusively with voice (9.9–18.7%). The attachment to the association of sound with voices creates a very limited centration of children's thinking which hinders any idea of sound as a physical entity. It should be noted that these children constantly distinguish sound from music.

Regarding the two tasks of the second RQ, an attempt was made to explore the subjective characteristic that is often attributed to sound by young children. Data analysis showed that children mainly refer to two basic subjective characteristics of sound: loudness and timbre. In particular, 14.3–19.8% of children satisfactorily distinguish these two characteristics and constantly express the mental representation of sound which own specific properties. A second category of children (58.2–61.5%) hesitated to recognize differences in sounds, and when they do so, it is usually for sounds with which they are familiar, such as the voices of friends and family members. Finally, a relatively high percentage of children (15.4–44%) seemed to face great difficulties in attributing subjective characteristics to sounds. This is compatible with the way they construct the concept of sound in their mind, as it is quite difficult for someone to attribute particular properties in something that is not recognized as a distinct phenomenon. These findings are consistent with similar previous studies where the production of sounds from different kind of materials has been explored [18,19,31].

In the three tasks of the third RQ, an attempt was made to highlight the mental representations of children for the production and the distinction of sound from its sources. In all three tasks, a group of children (12.1–18.7%) stated that sound can be produced in a number of different ways and propagates in space. A second group of children (65.9–68.1%), however, seemed to refer in a consistent manner to the association between sound sources and the receiver, while very few of them were able to recognize the existence of sound between them. These were children who seemed to be on the verge of transition from immediate transmission to reasoning with characteristics of operational transitivity. The recognition of the presence of sound between a source and receiver is also a finding of another study [28]. Finally, a third group of children (15.4–20.9%) insisted on the production of sound solely from voices and did not refer to any kind of propagation. A number of them seemed to recognize that apart from sources, voices only exist on receivers. These results are consistent with the findings of Piaget and Vergopoulo [27]. It should be noted, as mentioned above, that Eshach and Schwartz [15] stated that the way eighth-grade students conceptualize the notion of a wave or a medium affects the way they perceive both the nature of the sound and its propagation. Indicatively, a number of students who perceive sound as particles, draw different forms of particles in different media. In addition, students seem to attribute different mechanisms to the propagation of sound depending on the medium, for example, bubble-like in air, but ray-like in water (p. 759). In some cases, sound does not only seem to change form as it travels from one medium to another, but also the type of material through which is propagated is completely modified. However, given the fact that the present study did not make use of different mediums through which sound propagates, the effect of the medium on children's mental representations was not investigated. On the other hand, while the only medium that was available for discussion with children was air, it was apparent from relevant questions that children seem to recognize that sound is spread everywhere in space. Consequently, the construction of a mental transition step from the source to receiver seems likely to take place on children's thinking. Undoubtedly, it would be interesting in a future endeavor to investigate whether authentic ideas exist among preschool children related to sound propagation mechanisms.

Apart from dealing with the data of each research question separately, of particular interest was the finding of the stability of some children's reasoning which was expressed throughout all tasks. As shown in Table 9, eleven children (6, 14, 15, 31, 42, 46, 61, 69, 77, 84, 91) seemed to recognize, along all tasks, the propagation of sound in space and in particular its propagation from sources to receivers. This finding is important because it underscores the ability of children, even from this age, to form in their minds a mental representation of sound based on a logical two-step thinking pattern for the propagation of invisible physical interactions in space. It is this mental representation that allows a significant prospect of children to be initiated to the world of sounds, as it provides a solid path for the development of teaching activities that will enable children of this age to deal with sounds and their basic characteristics. However, it would be quite interesting for feature research to investigate which kind of experiences and interactions enable such a developmental pathway which in turn leads some children to construct operational transitivity for sound. In this direction, a distinct stream of Early Childhood Science Education seeks to study the conditions and prerequisites for the construction of precursor models—meaning stable entities of thought which have characteristics compatible with those of school physics [36].

After all, as shown in Table 9, several children, apart from these eleven, often responded to a number of tasks with satisfactory responses, such as P. 5 scoring 6/8 and P. 33, P. 12 and P. 90 scoring 4/8 sufficient answers. Undoubtedly, the mind of these children was dominated by the mental representation of immediate transmission of sound and that is why their involvement with specialized teaching interventions is important. In general, the development of teaching activities needs special care and scaling as many children have a long mental path to go through until the conquest of transitivity. For instance, children P. 1, P. 7, P. 30, P. 43, P. 48, P. 53, P. 71, and P. 86, who gave insufficient answers to all tasks, need special teaching interventions to succeed in separating the concept of sound and voice, something that is not necessary for other children. However, in general, central elements of children's average and inadequate reasoning are closely related to the perceptual data of the proposed situations and especially to the materials that create sounds, the human voice or the actions that lead to the sound's creation. The transition to a state of reasoning that recognizes sound as a physical entity presupposes activities of decentralization from these elements.

6. Conclusions

In the present research, an attempt was made to investigate the mental representations of children aged 5–6 years for sound. Based on the theoretical framework of Genetic Epistemology, it seemed that conceptualizing sound, as is the case of heat [27] or light [26,37], requires the construction of a two-step transitional reasoning. While this construction is not expected to dominate children's thought at this age, it was shown to be possible. The research findings dictate the development of appropriate teaching activities which are based on the present study, in order to form mental representations compatible with those of school-level Physics. An axis of research in Early Childhood Science Education is now oriented in this direction.

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Appendix A

In the appendix is presented Table A1 which shows the order of tasks in which they were presented to the children of the sample.

Table A1. The order in which the tasks were presented to children.

Order	Number	Task
1	1.1	What is sound?
2	1.2	Could you tell me some kind of sounds that you know?
3	2.1	Are all sounds the same? If not, where do they differ?
4	3.1	How are sounds produced, how are they made of?
5	2.2	Behind you there are some objects made of iron, wood and glass. I am going to hit two of them and I would like you to guess which one I am hitting each time. For example, if I hit these two objects made of plastic, they make that sound. Let's see if we can recognize the sounds without observing the objects that being hit.
6	3.2.	Where do the sounds go? If we produce a sound here on the table, inside the room, will it go somewhere else?
7	1.3	Is music a kind of sound?
8	3.3	Here we can see a mouse who sings and a rabbit who wants to hear her songs. I will show you some points to tell me whether her voice could be heard there (Figure 1).

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Temperature Measurement—Inquiry-Based Learning Activities for Third Graders

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Abstract: The article presents our Inquiry-Based Learning (IBL) activities in the project-based Science education of third graders (8–9-year-old pupils) in the Slovak Republic. Individual tasks of project assignment titled "Temperature Measurement" were conceived for "*guided inquiry*". We also supported the IBL of pupils by interactive education strategy–Integrated e-Learning (INTe-L). The strategy was built on the role of interactive simulations and experimenting at the knowledge acquisition. The following INTe-L components were used: (a) on-site and remote experiments, (b) interactive simulations and (c) electronic study materials. The research was based the hypothesis that the project-based teaching of the topic "Temperature Measurement" using the IBL activities is significantly more efficient than traditional (instructivist) way of teaching. To verify the hypothesis, we carried out a pedagogical experiment on a sample of 60 respondents. The third graders were divided into two parallel groups: an experimental group (EG, 30 pupils) and control group (CG, 30 pupils). To get a relevant feedback, pre-test and post-test were developed and applied. The results attained in the EG were statistically processed, evaluated, and subsequently compared with those in the CG. The analysis of the results attained by the EG showed that their knowledge acquisition has been increased by 24% compared to CG. We have created a methodology for making simple scientific project assignments with the implementation of all components of the new integrated e-learning education strategy (real and real remote experiment, e-simulation, e-learning material). On a specific example of the topic "Temperature Measurement" in primary education, we have presented the possibility of using a "guided inquiry" in the implementation of individual experimental tasks. We have introduced a form of teamwork that allows to harmonize the teaching requirements with individual learning approach and helps to prepare pupils for planned work and independent knowledge acquisition and problem solving. The study has shown that complex IBL activities can be successfully applied at primary school 3rd grade level already. Our form of education with the wider use of modern information and communication technologies (ICT) was attractive for the learners and helped them to develop interdisciplinary relationships. The integrated e-learning has helped third grades to develop a deeper conceptual understanding of temperature and allowed them to prepare presentations to demonstrate their conceptual knowledge. The approach allowed pupils to gain key competencies in Science (discussion and presentation of results). It has also increased the pupils' interest in Science in general and helped them to understand links between different subjects.

Keywords: integrated e-learning; inquiry-based learning; primary school; 3rd-grade pupils; project; Science; temperature measurement

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1. Introduction

People live in a society surrounded by a variety of information and communication technologies (ICT). Children operate their parents' television sets, mobile phones, iPads, and personal computers. They watch videos and play computer games since their early childhood. Their advanced knowledge of ICT is a natural consequence of a rapidly changing society. In this context, the following question arises: "How to integrate the ICT into teaching to actively engage pupils in the discovery of new knowledge?" The answer to the question is neither simple nor unambiguous. Teachers try to embrace the pupils' interest in ICT and facilitate its use at school. The effectiveness of the ICT usage, however, depends on the teaching methods, the teacher's personality, his/her pedagogical mastery, as well as on the nature and specifics of the subject. It also depends on the competence of the learner and their environment [1].

One option for how to improve the teaching of science is the use of Inquiry-based learning (IBL). IBL aspires to engage students in an authentic scientific discovery process [2]. The IBL is an educational strategy in which students follow methods and practices routed in professional science to construct knowledge [3]. It is an active, learner-centered approach focusing on questioning, critical thinking, and problem solving. The learner is actively involved in question formulation and its solution [4]. The use of ICT in IBL is not a goal, but a welcomed step forward in the process. The IBL represents a constructivist approach to science education [5]. It is viewed as an alternative means for the learning and understanding of scientific concepts. In IBL, the process of inquiry is the key element [6]. The IBL can positively affect the students' learning outcomes by enabling open inquiries [7]. It provides a unique opportunity to introduce thoughtful insights into already-known facts about the surrounding natural environment [8]. The IBL is meant to reflect the methods and processes of modern science as closely as possible. The essential component is the scientific experiment. The experiment helps pupils to grasp the very essence of real research and acquire new knowledge. The learning takes place in situations intentionally created by teachers, thereby enabling the pupils to observe real natural phenomena, manipulate specific objects, conduct experiments, engage in live discussions, and take an active part in practical problem solving [9].

IBL is often organized into inquiry phases that together form an inquiry cycle. However, different variations on what is called the inquiry cycle can be found in literature [2,10]. An example of the research activities hierarchy, adapted by the participants of the ESTABLISH project [11], is presented in Figure 1. It focuses on the following activities (from bottom to top): interactive demonstration, confirmation inquiry, structured inquiry, guided inquiry, and open inquiry. As young children have a limited cognitive processing capacity, they should be guided by their teacher. In "guided inquiry", the teacher establishes a problem to the learners and their role is to propose a concrete solution. The pupils' ability to use the previously acquired skills in solving new problems is tested during the problem-solving process. The problems are introduced through simple verbs, such as, "measure", "examine", "observe", "find out", or "define". The learners find these tasks easy to solve, and propose the problem-solving procedure themselves, only with a minimum guidance from the teacher [10]. The instructional strategies can be moved toward open inquiry. In the "open inquiry", the children are able to formulate their own questions and design their own investigations [12,13]. In open IBL, the teachers encourage their pupils to conduct a self-designed, interest-driven inquiry to find answers to their own research questions. It has been shown that minimal guidance during IBL does not work [14]. Therefore, the teachers' efforts during the process are directed towards facilitating, supervising, and supporting their pupils at the knowledge acquisition [15].

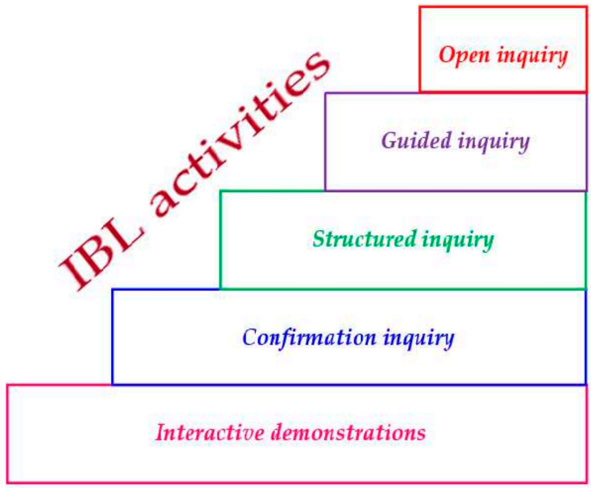

Figure 1. IBL activities.

Primary school pupils tend to be very curious and motivated to learn [13]. Cognitive and developmental psychology research studies have shown that environmental effects are important during early age development. The lack of stimuli at this time may lead to a child's underdevelopment [16]. Several researchers suggest that science education should begin in the early years of schooling [17–19]. To teach the scientific concepts efficiently, however, it is necessary to understand the nature of children's ideas about the world surrounding them. Young children tend to regard objects from a human-centered (self-centered) point of view. As such, they often attribute human aspects, such as emotions, to different objects and phenomena [20,21]. The children's misconceptions and alternative conceptions of scientific expressions are deeply rooted in their daily life experiences. Several different factors may influence the children's misconceptions of natural phenomena. Duit and Treagust proposed six possible sources for alternative children's conceptions: cultural background, language experience, sensory experience, mass media, peer groups, and science instruction [22]. A poor science instruction in early childhood may result in negative student attitudes and underperformance, and these difficulties may pertain well into college years [23]. The early exposure to science, however, can help children foster their scientific reasoning skills, encourage positive attitudes toward scientific subjects, and provide a solid foundation for their later academic studies.

Heat and temperature are difficult concepts for primary school children to understand because of their abstractness. Heat is defined as an energy that is transferred from a place with higher temperature to a region of lower temperature [24]. Heat has its roots in the thermal motion of atoms and molecules. It is a thermodynamic quantity that is represented by symbols and mathematical equations. Tang and Tan show that heat is defined as "a network of semantic meanings, assembled across multiple representation modes" [25]. Previous studies have indicated that young children had difficulties in making semantic links between different concepts used by the scientific community [26,27]. Scientific terms such as heat and temperature are often misunderstood [28,29]. Sozbili reviewed scholarly literature on students' misconceptions on heat and temperature [30]. The author found that students' misconceptions vary with age. The following misconceptions of students 6–13 years old have been identified: 1. There are two types of heat, cold heat and hot heat; 2. Heat is a material substance such as air or steam; and 3. The temperature of an object is related to its size. Thomaz, Malaquias, Valente, and Antunes observed that children had problems with identifying the nature of heat [31]. They believed that heat was a "substance" residing in physical objects. Their misconception originated from a fact that heat can be transported from one object to another. The concepts of heat and temperature are closely associated. The close association means that students have problems distinguishing between the two and use heat and temperature interchangeably in explaining thermal-related phenomena. Regarding the concept of temperature, Paik, Cho, and Go observed that students had difficulties linking it with a measurement of a physical quantity [26]. Some pupils thought of temperature as a material's property or physical instrument for heat measurement. The students also tended to summarize temperature the same way as heat [31].

It is now agreed that the learning of fundamental thermal concepts needs to address both semantic and semiotic challenges. Studies with pre-school and early school children related to concepts of heat and temperature focused on their understanding of water phase transformations [32–37]. Kambouri-Danos, Ravanis, Jameau, and Boilevin investigated a construction of a precursor model that can support children's scientific learning [33]. Their intervention had eight stages, during which children's predictions and explanations of water phase transformations were recorded. Russell et al. [35] and Bar [37] developed several activities related to water evaporation and used them to categorize children's mental representations. Previous studies also focused on demonstrating a thermal expansion of metals to children aged 5–6 [38], thermal conduction in metals [39], gasification [40], and combustion [41]. Furthermore, a recognition of a thermometer and its functioning was also explored [42]. The studies had a relatively short duration and a small number of activities due to the limited cognitive capacities of kindergarten children. An IBL approach in Preschool Science Education has been utilized by Cruz-Guzmán, García-Carmona, and Criado [43]. The science content taught to children aged 2–4 was related to the phase transformations of water and edible products (chocolate bar and ice pops). A positive evolution in children's conceptions and their ability to formulate predictions and to test them via experimentation have been noted [43]. Therefore, it has been suggested to implement IBL activities from the beginning of Preschool Education. Bar studied the views of children aged 5–15 on the water cycle [32]. The author found that children's conceptions of evaporation varied with age. It has been suggested that the teaching of the water cycle should be introduced around the age of 9, when some conception of evaporation has already been established. In a recent study, Yeo et al. used an image-to-writing approach to explain temperature and heat to primary school fourth graders (aged 9–10, [44]). The approach was guided by visualization techniques used by researchers. The authors exposed their pupils to images (photos, drawings, graphs) and asked them to describe their own thoughts about heat and temperature and translate them into textual representations using scientific terminology. The experimental group (EG) of primary school fourth graders received an inquiry-based instruction built on the image-to-writing approach [44]. In the control group, the pupils received a blend of direct instruction and inquiry activities without explicitly focusing on multimodal representations. It was revealed that a large fraction of pupils in the EG improved their levels of conceptual understanding after instruction. An image-to-writing teaching approach may help primary school pupils to develop a deeper conceptual understanding. They can use images as representations of their conceptual understanding of heat and temperature concepts. The approach is closely related to inquiry-based learning.

Inquiry-based science learning proved to be stimulating for students' motivation, research skills acquisition, and construction of meaningful conclusions [45]. IBL has been shown to correct students' misconceptions about energy and thermodynamics [46]. Nevertheless, the implementation of IBL in primary school classrooms may not be a simple task [47–50]. Zion et al. [15] mentioned that teachers often experience difficulties in supporting their pupils through the process of inquiry. The formulation of research question and investigation design are both challenging [47]. Therefore, the primary school teachers need to be taught how to use a new technology and how to support their students in project-based learning (PBL). Yet, they must also feel confident that their pupils are fully capable of this kind of active learning [49].

The major objective of our study was to determine the effectiveness of project-based science teaching with the support of IBL activities at primary schools. The results of the pedagogical experiment were compared with traditional (instructivist) teaching. The following research question has been formulated: What is the effectiveness of the Project-based teaching of the topic of "Temperature Measurement" in the third grade Science lessons in the selected primary school in the Slovak Republic using the IBL activities and the INTe-L strategy? In this paper, we describe our IBL activities of the "Temperature measurement" topic for primary school third graders aged 8 to 9. We believe the teachers will find the results of our study interesting and worthy of application in their pedagogical praxis.

2. Materials and Methods

2.1. The Problem of Research

In this paper, we aim to demonstrate a concrete example of IBL activities in the project titled "Temperature Measurement" in Science lessons for primary school third graders. We have designed the project for structured inquiry and supported the pupils' research activities with the latest ICT, as declared by the Integrated e-Learning (INTe-L) education strategy [51]. The main idea of the INTe-L strategy is based on the belief that when acquiring knowledge and skills in science, the pupils should follow the steps of scientific discovery [52]. They begin by observing the examined phenomenon, continue with their inquiry, and experiment with the aid of their teacher. Real on-site, real remote experiments, and virtual experiments (interactive simulations) can be implemented. Subsequently, the pupils process the acquired data and evaluate the results. The procedure ultimately leads to a confrontation of the theory acquired by pupils via textbooks and e-learning materials. The pupils thus evaluate the results, internalize concepts related to the issues they have examined, and finally find their way to a meaningful and deep understanding of physical phenomena and laws [53].

2.2. Methodology of Research

Our pedagogical research was conducted over a period of two consecutive years. In the first year, we carried out pre-research on a small sample—15 pupils of 3rd grade of primary school. The pre-research focused on verifying the possibility of using the IBL activities and INTe-L strategy in project-based teaching, detection of potential drawbacks, and determining whether the research instruments (pretest, posttest) would work. In our preliminary research, we studied whether the project work had the expected duration (1 week), the pupils understood the instructions and tasks, and whether they were able to finish the project assignment. The results of pre-research were not statistically evaluated due to the limited number of pupils.

The main research was conducted in the second year. During our pedagogical experiment, we used several methods. At the beginning, we started with a literature review. We used the literature review method [54] to review professional literature on IBL and to determine the state of the art in Slovakia and abroad. Later, we proceeded with the experiment. In our pedagogical experiment, we used the technique of parallel groups [55]. In this technique, we worked with two student groups: experimental and control. The group in which the IBL was used as the main teaching strategy was designated as experimental group. A group in which the IBL was not performed was designated as control group. Analysis and synthesis methods [56,57] were used in processing of research results. Finally, statistical methods [58] were used for statistical processing of obtained data and for evaluation of results.

To quantify the efficiency of IBL activities, we used a didactic testing. Two tests were designed: pre-test and post-test. Based on the evaluation of the pre-test results, we determined the level of students' entry knowledge that could affect the results of post-tests later (if they were very different in individual groups). Using a post-test, we determined and compared the level of output knowledge of learners in the control and experimental groups on the topic of "Temperature measurement". When creating non-standardized didactic tests (DT), we followed a general algorithm given in [59]. Namely, we determined the goal and framework content of each DT. Furthermore, we determined the test time and the number of tasks for each DT. We assigned weight to the tasks and determined the scoring for each DT. We preliminarily verified each DT. Finally, we had each DT assessed by a methodologist. Based on his recommendations, we performed the final adjustment of individual DTs.

We assumed that there was a relationship between the pupils' level of knowledge and the use of teaching methods, organization forms, and teaching resources used in the pupils' learning process. The following hypothesis was postulated:

Hypothesis 1 (H1). *Project-based teaching of the topic "Temperature Measurement" in the 3rd grade Science lessons in the selected primary school in the Slovak Republic using the IBL activities and the INTe-L strategy is more efficient than traditional way of teaching.*

2.3. Sample of Research

In one school year, we conducted a pedagogical experiment in science lessons of the 3rd grades (8–9 years old) in one Slovak primary school. The school was located in West Slovakia. The main objective was to determine the suitability of the project-based teaching using the IBL activities for the topic "Temperature Measurement". The sample was selected based on convenience sampling and consisted of one experimental group (EG, 30 pupils) and one control group (CG, 30) pupils. Pupils of the CG were taught by the traditional (instructivist) methods while pupils of EG were taught by the project-based Science teaching with the support of IBL activities and INTe-L strategy.

2.4. Instrument and Procedures

According to the State Education Program of the Slovak Republic (ISCED 1, 2011 [60]), the topic "Temperature Measurement" is included in the teaching topic "Heat and temperature". According to ISCED 1 [60], in this topic the pupils find out the answers to the following questions: "How can we measure the temperature?", "How does a thermometer work?", and "Which objects are hot and cold?". According to ISCED [60], the pupils should know at the end of teaching that they can first use a hand contact to estimate the objects temperature. Furthermore, they should know that the temperature is more precisely measured with a thermometer. They should be able to measure their body temperature with medical thermometer. Furthermore, pupils should be able to distinguish several different types of thermometers. Finally, they should be able to construct a simple thermometer using a glass bottle, water, straw, and plasticine and use it to measure water temperature.

We measured the entry-level of pupils' knowledge by a didactic pre-test since their prior acquaintance with the topic could influence their final results. Teaching in both groups took place in the same grade (3rd grade), in the same subject (Science), and the same topic was taught ("Temperature Measurement"). Furthermore, the teachers were equally qualified and had more than 10 years of school praxis.

Prior to the actual project execution, the pupils were acquainted with the project topic and its objectives and with the method of results assessment. The pupils in the EG worked in several small groups. After the project completion, there was a presentation of the results of the individual groups, followed by discussion and evaluation based on criteria given beforehand. As part of guided inquiry, we gave students a greater opportunity for freedom. Each group was free to choose the form of project presentation, either lecture or poster. The most frequently used form of pupils' presentation was the poster. The IBL activities are important for the pupil's development of higher order thinking skills. The learners' ability to analyze, synthesize, and evaluate information may be enhanced by visual representation, such as imaging [44] or modelling [61]. It is therefore advised to engage students in active demonstration of their knowledge using different media. Teachers should be encouraging the divergent thinking of their students and give them freedom to formulate their own questions. By active presentation of results, the students can acquire effective strategies for discovering and demonstrating the answers [62,63]. The higher order thinking skills gained during IBL activities in Science are also transferable to other subjects.

2.4.1. Inquiry-Based Learning Activities of the Project Titled "Temperature Measurement" (Project Assignment for EG)

Task 1. *Body temperature*

Answer the following questions (Figure 2):

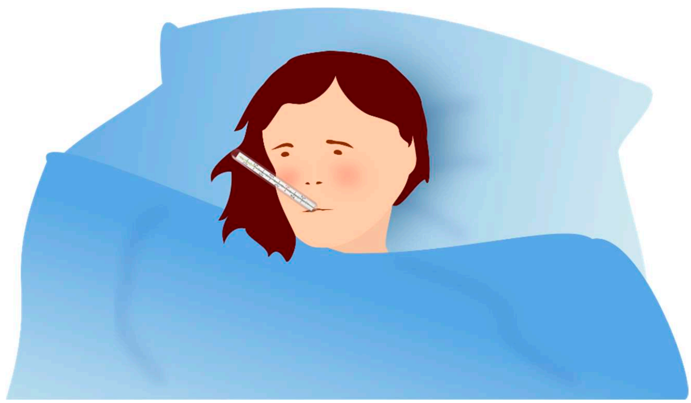

Figure 2. Feverish woman [64].

Look at Figure 2. What do you see? When was the last time you were ill? Did you have a fever? Who measured your body temperature? Which instrument was used to measure your temperature? What kind of thermometer was it? Can you measure your own body temperature? Do you know other kinds of thermometers? What can we measure with them?

Goal: To describe a real situation.

Task 2. *Objects with different temperatures*

Organize the objects in pictures (Figure 3) from the coldest to the warmest.

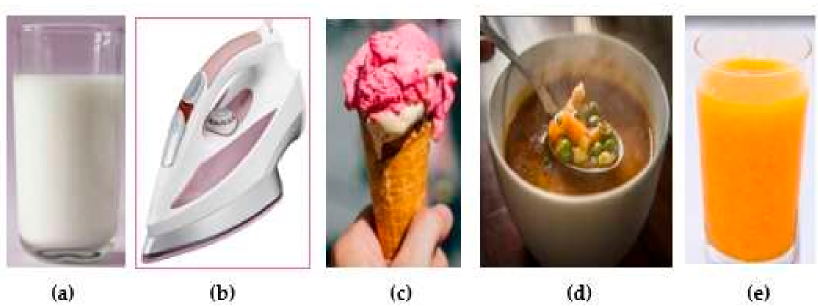

Figure 3. Pictures of objects with different temperatures (**a**) Hot milk [65]; (**b**) Iron switched on to the maximum [66]; (**c**) Ice cream [67]; (**d**) Hot soup [68]; (**e**) Orange juice [69].

Tools: Pictures of objects of different temperatures.

Procedure: Based on your own experience organize the objects on the pictures (Figure 3a–e) from the coldest to the warmest.

Goal: Based on personal experience, pupils are able to estimate temperatures of different objects.

Task 3. *Home-made thermometer*

Conduct the following experiment.

Tools: a test tube, a narrow glass tube, water, ink, food coloring, a cork with an opening for the tube, an electric kettle, two glass containers (e.g., beakers).

Procedure: Pour some cold water into the test tube and color it with a few drops of either ink or food coloring. What is the ink/food coloring in the water for? Insert the glass tube into the cork opening and then seal the test tube with the cork (Figure 4). Your teacher will heat up the water in an electric kettle for you. The teacher will pour the hot water into a glass container. Place the test tube with the ink (Figure 4) or food coloring into the glass container. Make assumptions about what is going to happen. Observe what is really happening. Describe and explain the changes that occurred during the experiment. Remove the test tube out of the glass container filled with hot water and immense it in another container filled with cold water. Make assumptions about what is going to happen. Observe what is really happening. Describe the changes and explain them. Have your assumptions been in agreement with what you really observed during the experiment? Based on the results of the experiment, explain the principle of thermometers.

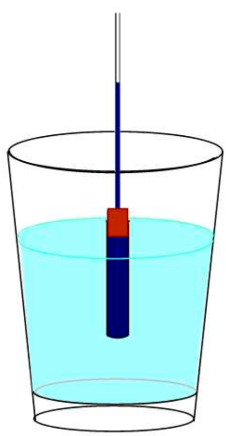

Figure 4. Home-made thermometer.

Goal: To explain the volume expansion of liquids depending on their temperature.

Task 4. *Heating of ice-cold water*

Conduct the following experiment.

Tools: a laboratory thermometer, drinking water (1 L), 2 glasses, ice cubes, electrical kettle, glass stick.

Procedure: Estimate the temperature of the water with some pieces of ice in it (Figure 5). Insert the laboratory thermometer into the iced water. Measure the temperature. Record the measured temperature in a table that has been prepared beforehand. Was your estimation correct?

Figure 5. Iced water in a glass [70].

The teacher will boil some water in an electrical kettle and pour it into the glass. Insert the laboratory thermometer into the glass of hot water and measure the temperature. Record it in the table. Slowly pour some hot water into the ice-cold water, stir it with a glass stick and measure the resulting temperature. Write down the measured water temperature. Describe what you just observed and formulate a conclusion.

Goal: To observe the change of water temperature in a glass container filled with ice by pouring warm water into the glass.

Task 5. *Experiment with interactive simulation titled "Energy Forms and Transformations".*

Tools: personal computer or iPad, Internet access.

Procedure: Click on [71] and open the interactive simulation titled "Energy Forms and Transformations" (Figure 6). Observe the temperature increase of individual objects on the interactive simulation. Find out the various ways to increase the temperature of objects in the interactive simulation.

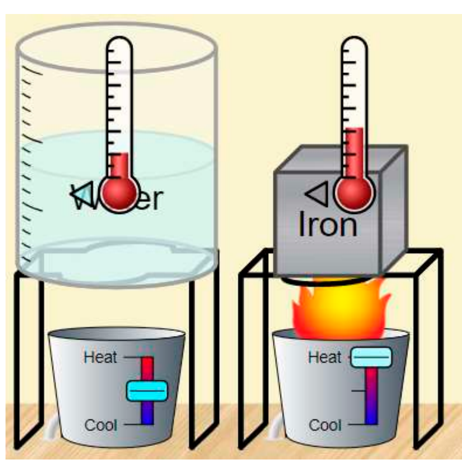

Figure 6. Interactive simulation of boiling process [71].

Observe the temperature decrease of individual objects on the interactive simulation. Find out the various ways to decrease the temperature of objects in the interactive simulation.

Goal: To demonstrate the increase and decrease of temperature by heating up or cooling down objects in an interactive simulation.

Task 6. *Different thermometers.*

Tools: The cards with names of different types of thermometers (Figure 7), pictures showing different types of thermometers (Figure 8a–d).

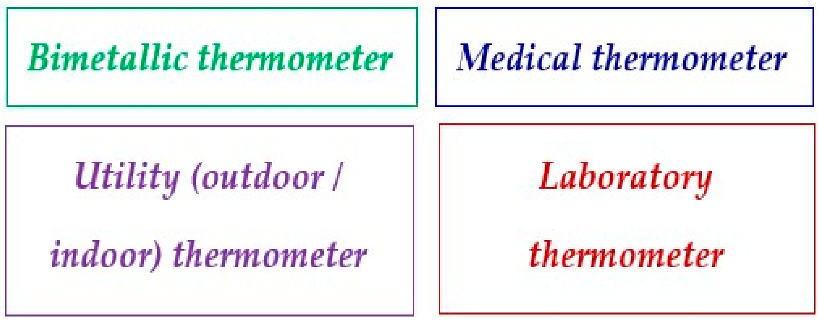

Figure 7. The cards with names of different types of thermometers.

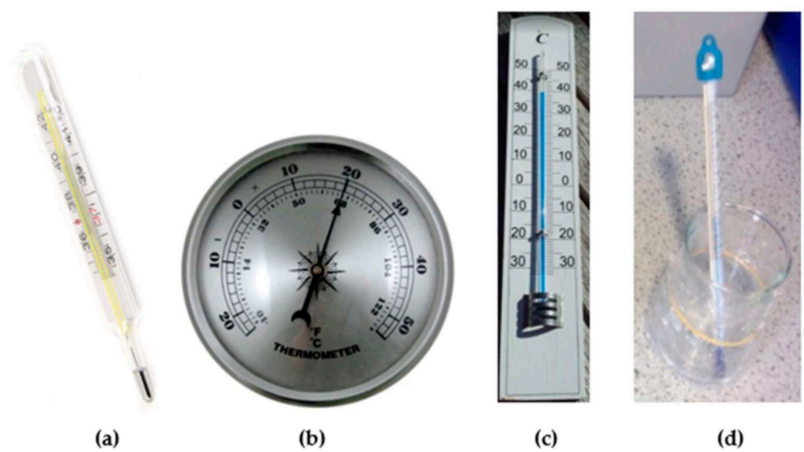

Figure 8. Different types of thermometers: (**a**) medical thermometer [72], (**b**) bimetallic thermometer [73], (**c**) outdoor thermometer [74], (**d**) laboratory thermometer [75].

Procedure: Assign the correct thermometer badges to the images.

Goal: To get familiar with basic types of thermometers.

Task 7. *Outdoor temperature.*

Tools: pictures showing certain weather conditions (Figure 9) and temperature cards (Figure 10).

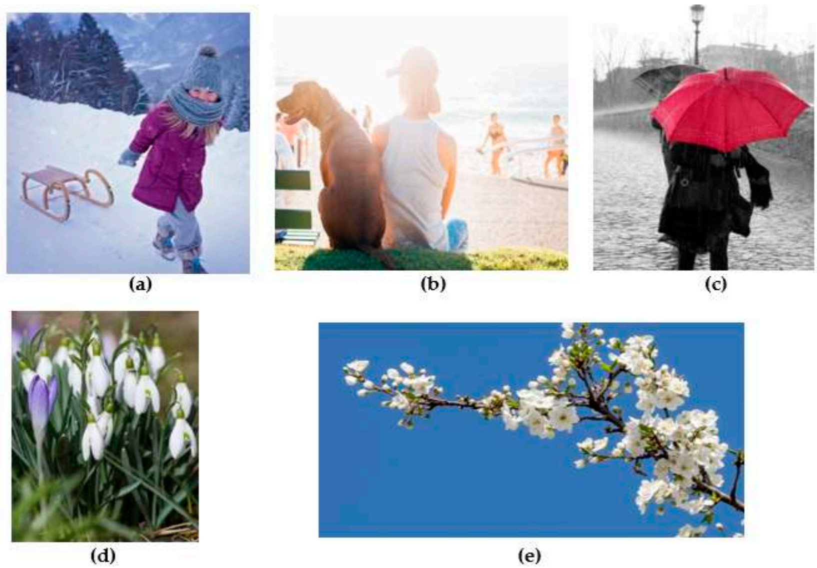

Figure 9. Different types of weather conditions: (**a**) sledging in winter [76], (**b**) sunbathing and swimming in summer [77], (**c**) rainy day in autumn [78], (**d**) snowdrops blooming in early spring [79], (**e**) flowering cherry tree in late spring [80].

33 °C	11 °C	–10 °C	21 °C	4 °C

Figure 10. The cards with different temperature values.

Procedure: Based on your personal experience, assign the appropriate temperature to the following images (Figure 9). Each image shows certain weather conditions.

Goal: Based on personal experience, pupils are able to assign the appropriate temperature to images displaying different weather conditions.

Task 8. *Weather pictograms.*

Tools: an outdoor thermometer, schematic weather symbols (Figure 11).

Figure 11. Schematic of weather symbols [81].

Procedure: By observing from the classroom window, estimate the outdoor temperature and determine the current weather conditions in the surroundings of the school. Using schematic symbols (Figure 11), write your findings down in a table prepared beforehand. Measure the actual temperature of the air by the outdoor thermometer and write down your findings in the table. Check whether the air temperature and the current weather you have estimated correspond to reality. Repeat the whole procedure once a day for one week. Discuss the weather changes that have occurred in the given period. When was the air temperature highest and when was lowest? When did you notice the largest difference in the air temperature? Is the air temperature related to current weather?

Goal: To be able to measure the air temperature at the school premises with an outdoor thermometer. To find out the current weather conditions and match it to the corresponding schematic symbol.

Task 9. *Monitoring of the actual weather conditions in a place where you live via internet.*

Tools: a computer or iPad, internet access.

Procedure: Open [82] and click on Weather–Current Conditions. Enter the name of your city/town/village into the search engine and find out the current air temperature in the place of your residence. Write down the acquired value in a table. Compare the air temperature of the place of your residence acquired from the Internet with the value measured directly with an outdoor thermometer in Task 8. Compare the values and explain the difference. Formulate the conclusion.

Click on [83] and answer the test questions. Check your answers.

Goal: To compare the air temperature from the place of pupils' residence, acquired in task 8, with the air temperature found out on the Internet during the same period. To formulate conclusions.

Task 10: *Monitoring of the actual temperature in a remote laboratory.*

Tools: a computer or iPad, internet access.

Procedure: Open the real remote experiment of the meteorological station in Klatovy, Czech Republic [84]. For one week, record the daily temperature in the laboratory of a real remote experiment in Klatovy at hourly intervals. From the values obtained, find out when the temperature in the laboratory was maximal and when it was minimal. What was the magnitude of the difference between the highest and lowest temperature?

Goal: To monitor the actual temperature in a remote laboratory over the internet. To formulate conclusions.

Task 11. *Based on the acquired information in the preceding tasks, prepare a project titled "Temperature Measurement".*

Project objectives within the study curriculum: Pupils become responsible for a specific task and cooperate during data acquisition, acquire data, evaluate them, discuss them, cooperate, and suggest solutions. Pupils present the data in a chosen format and without losing their informative value. Pupils measure the air temperature with thermometer, both on-side and remote. They record the measurement values in a table.

Time duration: 1 week.

2.4.2. Learning Activities of the Topic "Temperature Measurement" for CG

The teaching in the CG took place in the traditional instructivist way, in which the teacher was the "owner of knowledge", and the pupil was the "expected recipient". The teacher verbally explained the curriculum covered. After the formal introduction, the teacher demonstrated several experimental tasks to the pupils. He was a demonstrator and pupils were engaged in the experiments under his/her guidance.

Task 1. *Recognition of water temperature by touch*

Experimental tools: 3 water containers of different temperatures. The containers were arranged in the following order: warm tap water (40 °C) on the left, lukewarm water (20 °C) in the middle, water with ice cubes (0 °C) on the right.

Procedure: Pupils go to the teacher one by one and immerse one hand in a container of warm water, lukewarm water, and ice-cold water. Each pupil writes his observations in a notebook. Subsequently, they discuss the results they reached in carrying out the experiment. At the end, the teacher formulates a conclusion.

Goal: To find out if a person can use touch to recognize different water temperatures.

Task 2. *Recognition of thermometers.*

Tools: Pictures of different thermometers from Smart Notebook Gallery [63], interactive whiteboard.

Procedure: The teacher selects pictures of different types of thermometers from the Smart Notebook Gallery and places them on the interactive whiteboard. Pupils walk one by one to the blackboard and write the appropriate name under each picture of the thermometer. The teacher checks the correctness of their solution. Finally, the teacher explains to pupils the difference between different types of thermometers.

Goal: To identify different thermometers.

Task 3. *Construction of a simple thermometer.*

Tools: a test tube, a narrow glass tube, water, ink, food coloring, a cork with an opening for the tube, an electric kettle, two glass containers (e.g., beakers).

Procedure: The teacher constructs a simple thermometer using a glass bottle, water, a straw and plasticine. The teacher explains to the pupils that if this thermometer is immersed in hot water, the ink in the straw will rise. If it is immersed it in cold water, the ink in the straw will drop. Finally, the teacher explains to the pupils that all liquid thermometers work on the same principle.

Goal: To explain the volume expansion of liquids depending on their temperature.

Task 4. *Temperature measurement using laboratory thermometer.*

Tools: cold water, ice cubes, electric kettle, beakers, liquid-in-glass laboratory thermometer.

Procedure: The teacher pours some tapped cold water into the beaker and places ice cubes in it. The teacher measures the iced water temperature with a laboratory thermometer and records the value on the whiteboard. Teacher boils water in the kettle. He/she pours the hot water into an empty beaker, measures its temperature with a thermometer and writes the value on the board. Finally, the teacher explains to the pupils that the cold water in which the ice cubes float has a temperature of 0 °C. The boiling water (at normal atmospheric pressure) has a temperature of 100 °C.

Goal: To demonstrate the water temperature measurement with a general laboratory thermometer. To find out the actual water temperature.

Task 5. *Body temperature measurement with medical thermometer.*

Tools: medical thermometer, chalkboard, or Smart Board (interactive whiteboard).

Procedure: The teacher demonstrates a body temperature measurement. Each pupil measures his own body temperature with a medical thermometer and writes the measured value on a board. The teacher checks the accuracy of the measurement. From the measured values, pupils judge which of them has the highest and which the lowest body temperature. The teacher explains to the pupils what the elevated body temperature means. He/she also explains why the body temperature cannot be measured with meteorological or laboratory thermometer.

Goal: To be able to measure body temperature with a medical thermometer.

Task 6. *Measurement of air temperature in classroom.*

Tools: demonstration thermometer with an interchangeable scale (Figure 12), indoor thermometer.

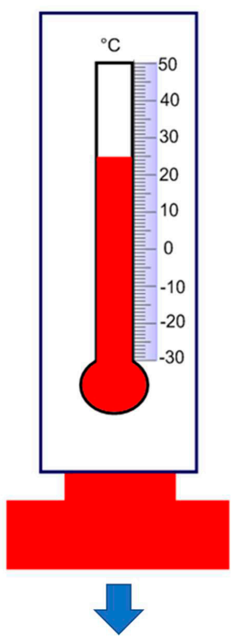

Figure 12. Demonstration thermometer with an interchangeable scale.

Procedure: The teacher controls the pupils' ability to identify the temperature measured on a demonstration thermometer. Pupils should correctly read the temperature, which is shown on the demonstration thermometer. Teacher also demonstrates the air temperature measurement in the classroom with a room thermometer.

Goals: To know that the room temperature is measured with an indoor thermometer. To be able to measure the air temperature in the classroom with a room thermometer.

Task 7. *Outdoor temperature measurement at school premises.*

Tools: outdoor thermometer, Smart Board interactive whiteboard, Smart Notebook Gallery.

Procedure: The teacher walks the pupils to the outdoor thermometer located at the school building. Pupils determine the air temperature at the school premises and write down their findings in a table prepared in advance. They also indicate the current weather conditions for the measured temperature by using weather pictograms listed in the Smart Notebook Gallery (Figure 11).

Goals: To know that the air temperature is measured with an outdoor thermometer. To be able to measure the air temperature at the school premises with an outdoor thermometer. To find out the current weather and assign it the appropriate schematic symbol from the Smart Notebook Gallery.

2.5. Data Analysis

Prior to carrying out the pedagogical experiment, we gave the pupils a non-standardized didactic entrance test (pre-test, Table A1 in Appendix A). By pre-test we studied the level of pupils' pre-entry knowledge. The pre-entry knowledge of the topic, if it was markedly different in the EG and CG, could influence the scores of the post-tests later. Since the number of test tasks was smaller than 20, we decided to use a weighted scoring [85]. The pre-test questions covered the Temperature Measurement topic described earlier. The pre-test had 15 questions, which were aimed at knowledge reproduction, but also required the participants to apply their personal experience gained in their everyday life by making decisions and looking for connections. The maximum achievable score in the pre-test was 45 points.

After the completion of the pedagogical experiment, we presented the EG and CG with a non-standardized didactic test (post-test, Table A2 in Appendix A). As the number of questions in the post-test was less than 20, we applied a weighted scoring method to evaluate the pupils' results [85]. The post-test questions covered the topic taught in the EG and CG. The post-test had 10 tasks, which aimed at knowledge reproduction, but also required the pupils to use their everyday life experience in finding connections and making decisions. The maximum achievable score was 30 points.

3. Results of Research

A graphical representation of the score distribution in the pre-test is given in Figure 13. The statistical evaluation of pupils' scores in the pre-tests is presented in Table 1. The results show the maximum and minimum score values, the sample count, the standard deviation, and the variance. The average pre-test score in the EG was lower compared to the CG. However, the difference was not significant. In the CG, the confidence level was 2.73, which means that with 95% certainty the distribution center lies within the interval 18.67 ± 2.73. The confidence level was 2.78 in the EG, which means that with 95% certainty the distribution center lies within the interval 17.63 ± 2.78. Based on the results, we can conclude that the distribution of pre-test score count in both CG and EG had a smaller kurtosis than the standardized normal distribution and was negatively skewed.

A graphical distribution of post-test scores is given in Figure 14. The statistical evaluation of pupils' scores in pre-tests is also presented in Table 2. The average post-test score in the EG was higher compared to the CG. The distribution of post-test results in both the EG and the CG had a smaller kurtosis than the standardized normal distribution and was positively skewed. In the CG, the confidence level was 2.57, meaning that with 95% confidence the center of the distribution lied within the interval 16.27 ± 2.57. In the EG, the confidence level was 2.67, which means that with 95% confidence the center of the distribution lied within the interval 20.17 ± 2.67. The average score achieved in the EG was thus higher by approximately 24% compared to the CG.

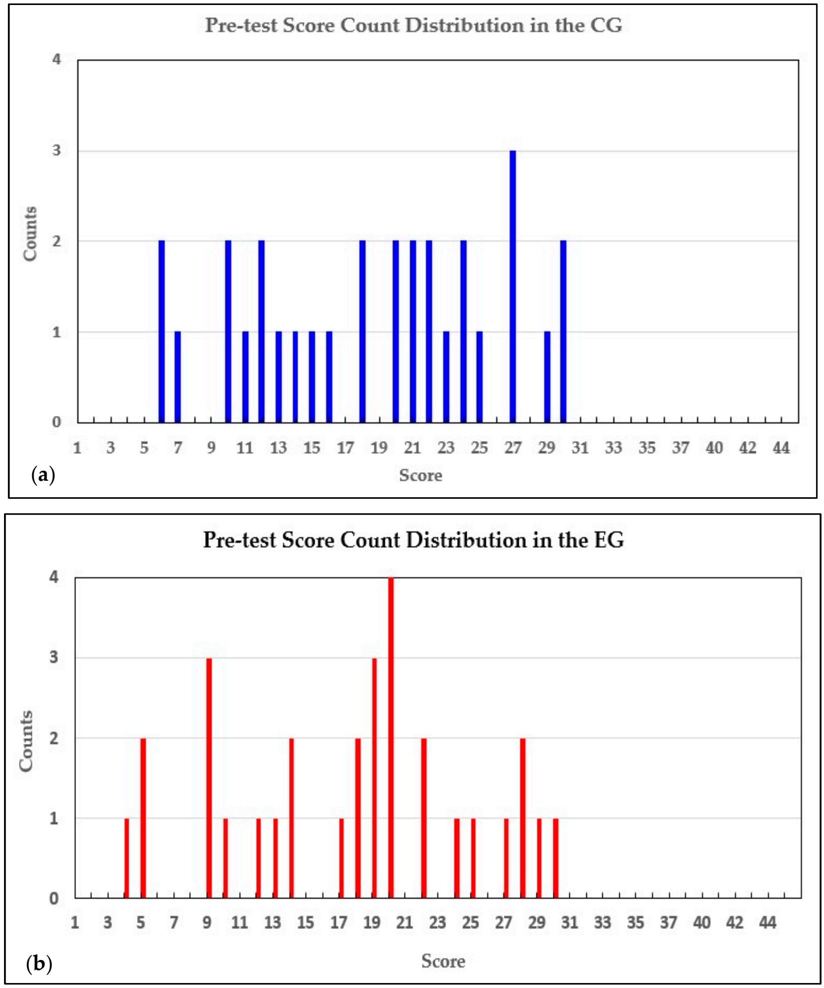

Figure 13. Graphical representation of the pre-test score count distribution in the CG (**a**) and EG (**b**).

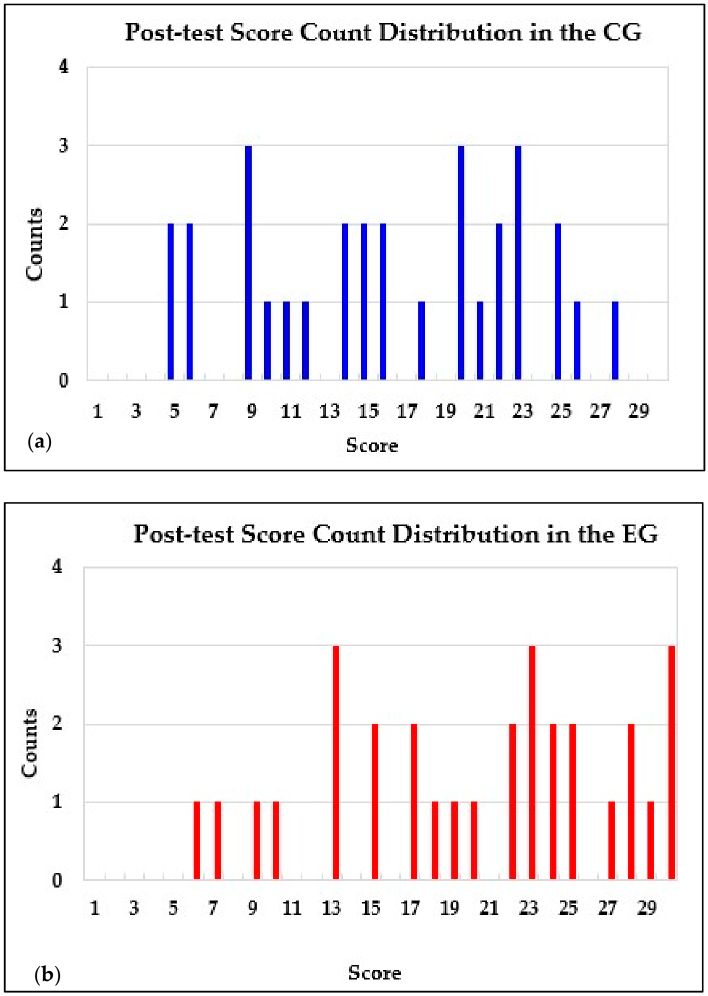

Figure 14. Graphical representation of the post-test scores in the CG (**a**) and EG (**b**).

Table 1. Descriptive statistics—pre-test (EG, CG).

Statistical Variables	Pre-Test	
	EG	CG
Mean	17.63	18.67
Error of the Mean	1.36	1.34
Median	19	20
Modus	20	27
Stand. Deviation	7.46	7.32
Sample Variance	55.62	53.61
Kurtosis	−0.82	−1.08
Skewness	−0.18	−0.17
Difference max.-min.	26	24
Minimum	4	6
Maximum	30	30
Sum	529	560
Count	30	30
Highest score	30	30
Lowest score	4	6
Confidence Level (95.0%)	2.78	2.73

Table 2. Descriptive statistics—post-test (EG, CG).

Statistical Variables	Post-Test	
	EG	CG
Mean	20.17	16.27
Error of the Mean	1.30	1.26
Median	22	16
Modus	23	20
Stand. Deviation	7.14	6.89
Sample Variance	51.04	47.44
Kurtosis	−0.87	−1.18
Skewness	−0.38	−0.14
Difference max.-min.	24	23
Minimum	6	5
Maximum	30	28
Sum	605	488
Count	30	30
Highest score	30	28
Lowest score	6	5
Confidence Level (95.0%)	2.67	2.57

3.1. Fisher—Snedecor's F-Test for Pre-Test

To find out whether the variance in both data sets was similar, we used a Fisher—Snedecor's *F*-test [85]. The test results are listed in Table 3. The variance was 55.62 in the EG and 51.58 in the CG. The chosen level of significance (α) was 0.05. The test criterion *F* was 1.08 (Table 3). Based on the results, we can observe that the critical value $F_{0.05}(29; 28)$ is 1.88 and the calculated value of *F* is 1.08. The calculated *F* value is lower than the critical value and, furthermore, $p > 0.05$. Therefore, the null hypothesis must be adapted. As such, we can conclude that there were no statistically significant differences in the variance in both groups and the application of Student's *t*-test with equal variances is therefore justified.

Table 3. Binomial *F*-test for Variance (EG, CG).

Statistical Variables	Pre-Test	
	EG	CG
Mean	17.63	18.31
Variance	55.62	51.58
Observation	30	29
Difference	29	28
F	1.08	
$P(F \leq f)$ (1)	0.42	
F crit. (1)	1.88	

3.2. Student's t-Test for Pre-Test

We tested the null hypotheses in the Student's *t*-test using the *t* criterion [85]. The results are presented in Table 4. The chosen level of significance (α) was 0.05. We compared the calculated value of *t* with the critical value of the test criterion for the chosen level of significance (0.05) and the corresponding number of the degrees of freedom, in our case $f = 58$. Based on the results given in Table 4, we can conclude that the critical value of Student's *t*-test for 58 degrees of freedom at the chosen level of significance is $t_{0.05}(58) = 2.00$. For the values shown in Table 4, *t* is equal to -0.54. Since the calculated *t* value is smaller than the critical value and, at the same time, $p > 0.05$, we must adopt a null hypothesis. Therefore, we conclude that there were no statistically significant differences between the pre-test scores of the EG and CG.

Table 4. Binomial *t*-test with Homogeneity of Variance.

Statistical Variables	Pre-Test	
	EG	CG
Mean	17.63	18.67
Variance	55.62	53.61
Observation	30	30
Common Variance	54.61	
Hyp. difference of Means	0	
Difference	58	
t stat	−0.54	
$P(T \leq t)$ (1)	0.30	
t crit (1)	1.67	
$P(T \leq t)$ (2)	0.59	
t crit (2)	2.00	

3.3. Fisher—Snedecor's F-Test for Post-Test

To find out whether the variance in both data sets was of the same size, we used the Fisher-Snedecor's *F*-test [85]. The results are displayed in Table 5. The chosen level of significance (α) was 0.05. The variance of the results in the EG was 51.04. The variance of the results in the CG was 47.44. The test criterium F = 1,08. Based on the results (Table 5), we can conclude that the critical value $F_{0.05}(29; 28) = 1.86$ and the calculated value $F = 1.08$. We found that the calculated *F* value was lower than the critical value and $p > 0.05$. As such, we adopted the null hypothesis, i.e., there were no statistically significant differences in the variance in both groups, and the application of Student's *t*-test with equal variances is therefore justified.

Table 5. Binomial *F*-test for Variance (EG, CG).

Statistical Variables	Post-Test EG	CG
Mean	20.17	16.27
Variance	51.04	47.44
Observation	30	30
Difference	29	29
F	1.08	
$P(F \leq f)$ (1)	0.42	
F crit. (1)	1.86	

3.4. Student's t-Test for Post-Test

We tested the null hypotheses in the Student's *t*-test using the *t* criteria. The results are presented in Table 6. The chosen level of significance (α) was, again, 0.05. We compared the calculated *t* value with the critical value of the test criteria for the chosen level of significance (0.05) and the corresponding number of the degrees of freedom, in our case $f = 58$. Based on the results, we can conclude that the critical value of Student's *t*-test for 58 degrees of freedom at the chosen level of significance was $t_{0.05}(58) = 2.00$ For the values listed in Table 6, *t* equals 2.15. As the calculated *t* value is higher than the critical value and $p < 0.05$, we must reject the null hypothesis. An alternative hypothesis is therefore valid, which means that between the post-test results of the EG and the CG, there was a statistically significant difference.

Table 6. Binomial *t*-test with Homogeneity of Variance.

Statistical Variables	Post-Test EG	CG
Mean	20.17	16.27
Variance	51.04	47.44
Observation	30	30
Common Variance	49.24	
Hyp. difference of Means	0	
Difference	58	
t stat	2.15	
$P(T \leq t)$ (1)	0.02	
t crit (1)	1.67	
$P(T \leq t)$ (2)	0.036	
t crit (2)	2.00	

4. Discussion

The Student two-phase *t*-test with dispersion equality proved that differences in the pre-test between the EG and the CG were not statistically relevant. Nevertheless, the differences in the final didactic test (post-test) between the EG and the CG were statistically relevant, i.e., there was a statistical dependency.

A comparison of pupils' achievements in the EG and the CG is presented in Figure 15. The difference between the groups in the amount of knowledge gained is remarkable. The average score in the CG was improved by 12% after the instructivist teaching. In the EG, the score has been improved by 25% (Figure 15). It shows the higher efficiency of inquiry-based learning compared to the instructivist approach.

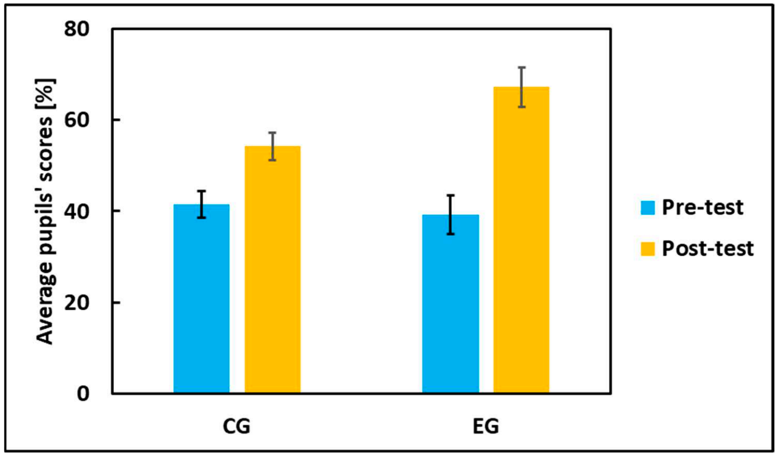

Figure 15. A comparison of average pupils' EG and CG scores in pre-test and post-test.

The analysis and evaluation of the pupils' results show the appropriateness of the introduction and wider implementation of project-based learning, using the IBL activities introduced into the educational process of the 3rd graders at Slovak primary school for the topic "Temperature Measurement". The pedagogical research verified the postulated hypothesis at the level of significance $\alpha = 0.05$. The students' learning skills have been improved by 24% compared to the control group. As such, we can say that the project-based teaching using the IBL activities for the topic "Temperature Measurement" was more efficient than the use of a traditional (instructivist) way of teaching.

Kostelníková and Ožvoldová [86] conducted a similar research study on a sample of 156 Slovak primary school pupils (69 boys and 87 girls aged 11 to 13 years). Their research evaluated the effectiveness of IBL with the combination of real remote experiments in the topic "Weather forecast-temperature measurement". The results of their study proved the effectiveness of the proposed methodology. The IBL, in combination with real remote experiments, resulted in better post-test scores of the experimental group compared to the control group. The pupils' skills in data recording and evaluation, i.e., how to plot a graph, how to read it, and how to calculate average values, were significantly improved. The noted improvement was related to the active involvement of the students in the construction of their knowledge. Moreover, the authors found predominantly positive attitudes of the pupils towards real remote experiments.

Our initial experience with IBL activities in Project-based Science education using the INTe-L strategy in science education with a focus on structured inquiry at the primary level was positively received. The pupils were able to solve the assigned tasks, and to develop, present, and defend their projects. Furthermore, our survey has also shown that pupils found the topic appealing. The pupils in the EG were asked to express their views on temperature measurement teaching at the end of the activity. The IBL activity for most of them was interesting (67% respondents), and they said they found new information about temperature measurement (63% respondents). We also asked pupils what they would change in the science teaching if they had the possibility. In response, 50% of pupils said they would like to conduct more experiments, 45% would not change anything, and 5% would like to bring live animals to science class.

Consistent with the findings of our pedagogical research, previous studies also reported positive outcomes when PBL was used as a teaching model. For instance, the quantitative findings of study [87] realized in Kuala Lumpur, Malaysia, indicated that students exposed to the PBL curriculum outperformed the students who were taught using instructivism. The obtained interview responses further confirmed the positive outcomes of the quantitative findings. The findings of the previous studies focused on energy education [51,84] suggest that project-based energy education significantly improves students' energy literacy. Furthermore, students taught using the PBL were found to take their learning more responsibly [87]. The PBL was used as an action-oriented method for developing pro-environmental behaviors of Turkey's pre-service teachers [88]. For instance, an improved content knowledge on ecology and scientific investigation skills was reported among high school students when they participated in an intertidal monitoring project building study [89]. Science, Technology, Mathematics, and Engineering PBL instruction of high school students resulted in improving the low-performing students' understanding of Mathematics [90].

Through a project-based activity, the research conducted by Lin, Kuen-Yi; Lu, Shao-Chuan [91] explored how science education activities improve the energy literacy of third-year students in a senior high school in Taiwan. The PBL has been widely applied to stimulate learning motivation, cultivate implementation capability, and improve learning effectiveness [92]. The researchers have also indicated that employing proper educational technologies or learning strategies could further improve students' performance [93].

The process of inquiry is not a simple, straightforward process. Based on the curriculum and the nature of the investigation, the educator may emphasize different learning stages. Inquiry learning is a continuous activity as a single session rarely includes all inquiry stages [94]. Both scientists and teachers find it stimulating for pupils and beneficial for the development of their research skills and the construction of permanent scientific knowledge [47,95]. The scientific inquiry and project-based learning can foster the pupils' ability to work, think, and act as scientists and communicate science as an important aspect of their soft skills.

5. Conclusions

Temperature and heat are challenging concepts for primary school children because of their abstractness. Previous studies have shown that young children had difficulties in making semantic links between different conceptions used by the scientific community [26,27]. Scientific terms such as heat and temperature were often misunderstood [28,29]. Regarding the concept of temperature, Paik, Cho, and Go observed that students had difficulties linking temperature with a measurement of a physical quantity [26]. Some pupils thought of temperature as a material's property. They also tended to summarize temperature the same way as heat [31].

It is now agreed that the learning of fundamental thermal concepts needs to address both semantic and semiotic challenges. An instructivist education of thermal concepts has traditionally used a textbook-based instruction. The text-based instruction, however, is limited in science teaching as learners are only involved as passive recipients of knowledge. In a previous study an image-to-writing approach in teaching of temperature and heat has been used [44]. Driven by the visualization practices of scientists, different modes of images (photos, sketches) were utilized to unveil the meanings of heat and temperature at the macroscopic level. The study has shown that the active demonstration has a potential to help pupils in gaining a conceptual understanding of thermal concepts. Nevertheless, knowing the rules of formal representation is not sufficient for developing deeper conceptual understanding of complex physical phenomena. The present paper shows that a more complex approach to teaching of thermal concepts should be utilized. It presents an application of the research-based method in the strategy of education. On a specific example of the topic "Temperature Measurement" in primary education, we have presented the possibility of using a "guided inquiry" in the implementation of individual experimental tasks. We have created a methodology for making simple scientific project assignments with the implementation of all components of the new integrated e-learning education strategy (real and real remote experiment, e-simulation, e-learning material). We have introduced a form of teamwork that allows teachers to harmonize the teaching requirements with individual learning approaches and helps to prepare pupils for planned work and independent knowledge acquisition and problem solving.

Teachers should stimulate their students' learning abilities by asking questions that activate their prior knowledge. The questions should be open-ended and focus the pupils' attention on scientific problem solving. Such questions promote the learners' text comprehension and improve science learning. Teachers should also invite their pupils to engage in discussions and make reasonable predictions. They should support students in applying the formal language system of science to make meaning of the physical phenomena around them. The integrated e-learning helped third graders to develop a deeper conceptual understanding of temperature and heat. It allowed them to prepare presentations to demonstrate their conceptual knowledge. The approach helped pupils to gain key competencies in Science (discussion and presentation of results). It has also increased the pupils' interest in Science and helped them to understand links between different subjects. To our best knowledge, the wider implementation of ICT in the inquiry-based learning of temperature and heat concepts for third graders has not been reported yet. Our approach is thus both novel and effective. Information and communication technologies can be effectively integrated into inquiry-based learning. An active inquiry-based learning involves an observation of natural phenomena. Modern ICT can be used to allow pupils to make their own observations. Real remote experiments accessible via internet can be used to observe natural phenomena over time. The e-learning can be integrated in primary school science education to provide an effective and clear instruction that supports young children's comprehension of causal mechanisms.

The goal of Science teaching is to provide a certain amount of knowledge. Nevertheless, it is also important to prepare pupils for an independent knowledge acquisition and problem solving. It is thus desirable to develop pupils' creative thinking, imagination, reasoning, and logical thinking, as well as to raise their interest in Science. The teaching helps them to verify a certain fact and substantiate it. Project-based teaching with IBL activities using the INTe-L strategy makes the teaching process more attractive. During the PBL process, the pupils have an opportunity to improve their soft skills, i.e., they learn to search for, sort, and process information that could be useful in their future life. It is therefore desirable to conduct further pedagogical studies aimed at verifying the effectiveness of the PBL with the support of IBL activities, including the INTe-L strategy, for other Science topics and other primary school subjects.

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Institutional Review Board Statement: No personal information was collected from human participants, and data presented in this paper are not traceable to individual participants. All procedures involving humans were in accordance with the ethical standards of the institutional and/or national research committee.

Informed Consent Statement: Informed consent was obtained from all individual participants included in the study.

Data Availability Statement: Data are available from the authors.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Pre-test task definition.

Question no.	Definition
1	Fill in the correct word in the next sentence. A thermometer is used to measure . . . . (a) heat (b) temperature
2	Write two types of thermometers you know. . . . .
3	Circle the correct answer. A dimension of temperature is: (a) kilogram (b) degree Celsius (c) meter (d) liter
4	Write down the value of a person's normal body temperature. . . . . °C.
5	Fill in the correct word, either heat or temperature. A hot soup has a high .... From sun to frozen river a .... can be transported If it is cold outside, the thermometer shows a low . . . .
6	Answer the following questions: What happens to liquid water if we place it in a freezer? . . . . What happens to an ice cube if it is placed in a cup of hot tea? . . . .
7	What happens to liquid water when it boils? Mark the correct answer. (a) bubbles (b) changes color (c) nothing
8	Circle the correct answer: When water boils it changes to (a) an ice (b) a steam
9	Imagine that we make the following experiment: 1. We fill a transparent bowl with warm water. 2. We place a cold lid on the bowl. Write down what you would observe on the underside of the lid. . . . .
10	Of the following values, the air has the lowest temperature when the thermometer shows: (a) −3 °C (b) 0 °C (c) −15 °C
11	Arrange the following temperature values from highest to lowest. (a) 8 °C (b) −12 °C (c) 24 °C (d) −3 °C
12	Assign the correct characteristics of year seasons A–fruits are harvested, leaves fall off B–snow melts, trees are green C–flowers blossom, air is very hot D–water freezes, daylight is short spring: . . . . summer: . . . . autumn: . . . . winter: . . . .

Table A1. *Cont.*

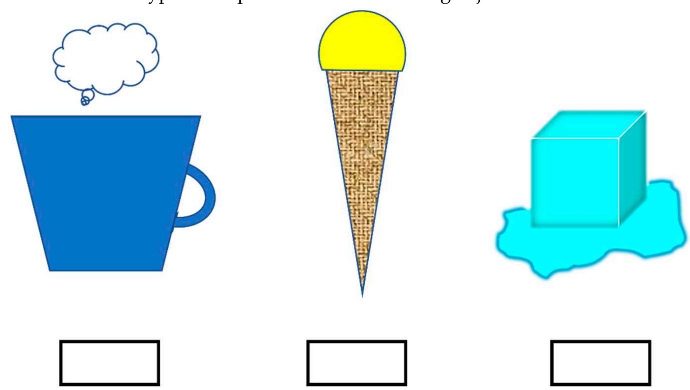
Question no.	Definition
13	Assign the correct temperature to each season. (a) 5 °C (b) −15 °C (c) 35 °C (d) 25 °C spring . . . . summer . . . . . . autumn . . . . winter . . . .
14	Circle hot objects on the following list: (a) Ice cream (b) Burning candle (c) Ice cube (d) Boiling water
15	Write down the typical temperature of the following objects 

Table A2. Post-test task definition.

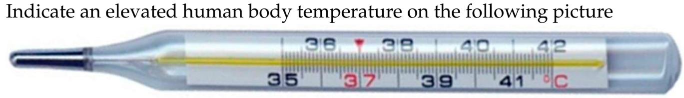
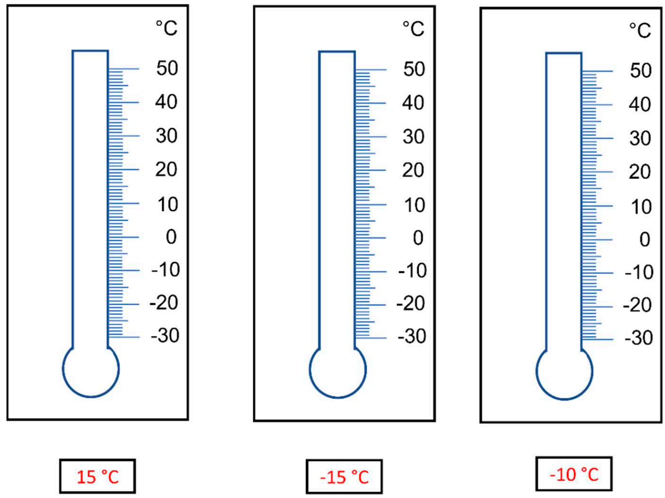
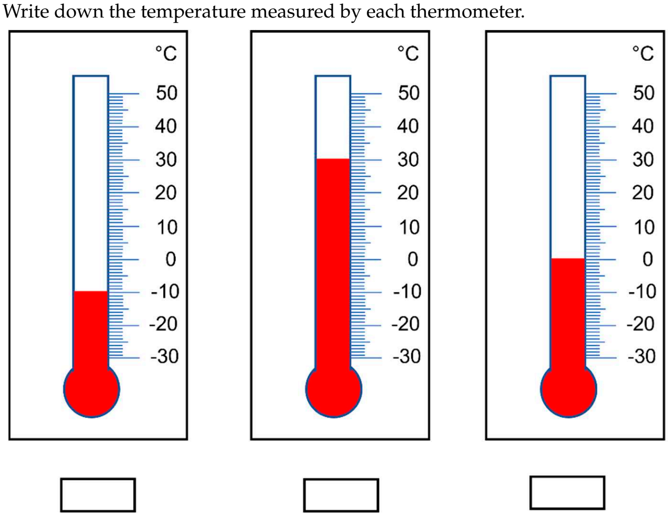
Question no.	Definition
1	Name 4 types of thermometers that you know. . . . .
2	What temperature value would a medical thermometer show if you had a fever? Underline the correct answer from the options provided. (a) 36 °C (b) 39 °C (c) 37 °C
3	Indicate an elevated human body temperature on the following picture 
4	Fill in the correct answer: (a) the boiling point of water is . . . . °C. (b) the melting point of ice is . . . . °C.

Table A2. *Cont.*

Question no.	Definition
5	Mark the measured temperature value on the scale of each thermometer. 
6	What can be a temperature of a snow flake? Mark all alternatives: (a) -5 °C (b) 13 °C (c) -3 °C (d) 20 °C
7	If we mix boiling water with iced water the resulting water temperature can be: (a) 0 °C, (b) 20 °C, (c) 100 °C, (d) smaller than 100 °C, (e) higher than 0 °C Mark all possible answers.
8	Underline the correct answer: We measure the body temperature body using: (a) room thermometer, (b) medical thermometer, (c) bimetallic thermometer, (d) any thermometer, that is not damaged.
9	Write down the temperature measured by each thermometer. 
10	Explain why an outdoor temperature cannot be measured by medical thermometer. …

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education sciences

Review

Perezhivanie and Its Application within Early Childhood Science Education Research

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Abstract: Perezhivanie is a concept that was originally defined by Vygotsky, but it did not become a part of educational theory until recently. Today the concept has been revived, and it is now used as a way to include emotional aspects into education and educational research. The concept also provides a rationale for describing and forming personalised learning. The present study provides a literature review with the aim of covering the variety in definitions of the concept, as well as the different perspectives that the concept lends to research in general, and to research with focus on early years education in particular. Results show that the concept has been applied within the most common theoretical perspectives in use today (such as social, cultural and subjective perspectives) with an interesting array of outcomes, such as design of educational methods, analysis of different modes of experiencing and development of self-awareness. The use of this concept becomes a shift toward more emotional perspectives of learning and development that may not be altogether positive, as perezhivanie holds the risk of blurring the border between psychotherapy and education, which is something that would provide new challenges for education in general and especially for teacher education.

Keywords: early childhood; perezhivanie; science education

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1. Introduction

Perezhivanie is a concept that was defined in Vygotsky's work [1,2]. In its most general sense, it is a concept that has been used to describe the reasons for individual differences, in what people focus on and how they then interpret this information [3]. Despite its potential importance for educational theory, the concept was only recently revived in contemporary research literature.

Today, the concept is used for holistic analysis of learning and development, as it provides a way to move beyond the dualism between the individual and the community [4–7]. This is a concept that could place focus on subjectivity in both learning and development but may also hold the promise of far more overarching conclusions of what may affect learning over the course of a lifetime [8]. The concept provides the logic to describe personalised learning outcomes, something that not only may help us gain insight regarding what children learn today, but also provide a rationale for analysing past and future learning [8]. The concept has been interpreted, developed and used by many researchers over the last decade, and in this process, it has diversified [9]. The purpose of this literature review is to explore the contemporary literature that includes the concept of *perezhivanie*. The aim is to find the diversity of applications and what the concept has to offer to educational research in general and to early years education in particular.

2. Background

As with many concepts, perezhivanie has been altered along the way, but in all its diversity, there are two characteristics which are generally accepted. The first one is that perezhivanie is generally used to understand individual differences in what people focus on and how they then interpret this information. Perezhivanie means to understand "how a child becomes aware of, interprets and emotionally relates to a certain event" [10]. These individual interpretations are not seen as merely reflections of the external world, but instead as transformations, that is, products of creative internal activity, as refractions [11]. The concept can be used for describing why the same situations are interpreted in different ways by different people.

The second aspect relates to the processes through which *perezhivanie* itself changes. Changes in perezhivanie are suggested to be the result of emotionally charged experiences leading to changes in the way in which we relate to the surrounding environment. In current literature, various expressions have been used to refer to these emotionally charged experiences, such as "dramatic perezhivanie" [12], "predicament" [8] and "experiencing-as-a-struggle" [13]. The origin of these emotionally charged experiences may be both coincidental and consciously planned as in education or through psychoeducation, psychotherapy and art. Examples of coincidental *perezhivanie* are found in unplanned, life-changing events, such as living in exile or growing up with alcoholic parents [8]. Conscious *perezhivanie* can be planned activities that become the driving force of children's motivation [14].

3. Method

A Web of Science search was performed on the 9 of April 2021 with the word "perezhivanie" as the topic. The search rendered 98 hits. From these ninety-eight papers, twenty-one were excluded (see Table S1). The reasons for exclusion were the language (three were written in Russian, one in Portuguese, and one in Spanish), the type of text (eight consisted of just an introduction or a short commentary) or because they were irrelevant to the goal of the present review (eight). The eight articles deemed irrelevant were omitted because they diverged from the goal of understanding how perezhivanie is currently situated in Early Childhood Education. Three articles were related to concurrent problems of acting in the context of Stanislafki's theory [15–17]. Other topics were learner readiness of security officers-to-be [18], the issue of national and cultural self-determination of L.S. Vygotsky [19], the notion of soperezhivanie [20] and a statistical analysis between professional well-being and risk of turnover in early childhood professionals [21].

Nine articles, which did not show up in the Web of Science search, but were relevant to the purpose of this review were introduced manually. These articles were added because they provided essential information about the notion of perezhivanie [12,22], play-worlds [23–28], and the theoretical work of Rey [29].

The first article included was published in 2003, with an increasing number of published works over the ensuing seven years, and the highest number of articles, 24, was published in 2016 (see Figure 1).

A thematic analysis [30] was used for categorising the articles as described in Table 1:

Table 1. Means for establishing trustworthiness at each phase of the thematic analysis.

Phases of Thematic Analysis	Means of Establishing Trustworthiness
Phase 1. Obtaining data	Store raw data in well-organised archives
Phase 2. Generating initial codes	Researcher triangulation
Phase 3. Searching for themes	Diagrams making sense of theme connections
Phase 4. Reviewing themes	Test for adequacy returning to raw data
Phase 5. Defining and naming the themes	Team consensus on themes
Phase 6. Producing the report	Describing the analysis process in detail

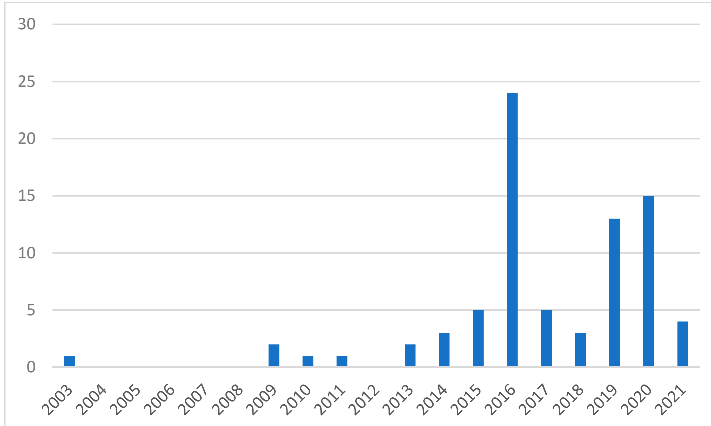

Figure 1. Number of papers from the literature search that were published each year.

After the literature search, initial codes were generated by an initial familiarisation of the remaining 85 papers. Three major categories were derived based on the kind of theoretical perspective used, with the first category being the social perspective (26 articles). This category included all articles in which *perezhivanie* was described as a social event. The sociocultural perspective (10 articles) included articles in which *perezhivanie* was connected to cultural mediation. The category called the subjective perspective (28 articles) included all articles in which the individual's internal interplay of meanings was in focus. Some articles that included both the sociocultural and the individual approach were defined as mixed (9 articles). Seven articles could not be categorised in any of these three categories due to the originality of the content. This initial analysis was performed separately by two of the authors, and then the results were compared.

To make sense of similarities within categories as well as connections between categories, a range of different parameters were used, such as direct reference theorists, use of concepts, as well as the methodological choices made by the different authors.

For example, the articles categorised in the social perspective conceptualised *perezhivanie* in the same manner as Veresov and Fleer [4]. Here, *perezhivanie* is used in connection with the concepts of the general genetic law of human development, the social situation of development, the real-ideal form, and the notion 'dramatic perezhivanie' [11]. The articles categorised in the sociocultural perspective conceptualised *perezhivanie* in the same manner as Ferholt, Nilsson and Clara [31,32]. *Perezhivanie* is here used in connection with the concepts of symbolic mediation, cultural artifacts, and the social construction of reality. The articles categorised in the individual perspective were mostly influenced by the works of Rey, Roth & Jornet, and Poole & Huang [33–35]. Here, *perezhivanie* is linked to subjective senses, subjective configurations and funds of identity.

The articles were then divided into observational research and intervention-based research, and a second analysis was conducted to ascertain the different ways *perezhivanie* has been operationalised in the literature and to test the categories for adequacy. Then, a third analysis was performed of the 22 articles that were focused on early childhood studies, and consensus on the categories was reached.

4. Results

4.1. Observational Research Papers

4.1.1. Research within the Social Perspective: Social Roles

In the social perspective, *perezhivanie* is identified in combination with concepts such as the general genetic law of human development, the social situation of development, the real-ideal form and the notion 'dramatic perezhivanie' [11]. The social environment is here seen as the source of personality and *perezhivanie* as formed by emotionally significant events, events that are instigated by the social environment. In this perspective, a child's *perezhivanie* is a combination of all the significant events that occurred in his/her past. The fields that are explored in this perspective are emotional regulation, school transition, role-playing games, children's scientific thinking, and science and technology in education.

Observational research mostly influenced by this theoretical perspective highlights the social character of experiencing and learning. Here, terms such as "role adjustment", "social identity", and "reader identity" are used for referring to how children "acquire behaviour patterns (i.e., behaviour adjustment), build emotional identification of the roles (i.e., emotional adjustment) and learn how to position themselves within a group (i.e., social adjustment)" [36,37]. In educational research in particular, it describes specific socially instigated events that cause change. The actual changes themselves include moving from a self-centered behaviour to a collaterally-centered behaviour [38,39], development in the way children conceptualise natural phenomena [40] or a change from "self-focused" toward "child-focused perezhivanie" when describing parental development [41]. The social-emotional interactions that cause or influence changes have been described as social roles [39] and peer interactions with older children, parents or teachers [39]. Also, one's personal sense of belonging to a group holds social meaning, and this can be a cause for change [42], as well as playing computer games together, where the difference between real-life and game characters is seen as a source for change [43].

4.1.2. Research within the Sociocultural Perspective: Perezhivanie as the Result of Mediated Cultural Representations

In the sociocultural perspective, the world is viewed as a sociocultural environment, meaning that everything has a meaning and carries cultural content. Here *perezhivanie* is connected to the concept of mediation. Within this perspective the individual does not form a direct relationship with the environment; instead, "the subject's agency is mediated by cultural means in the transformation of the object" [31]. Signs, concepts, discourses, cultural representations, traditions and artifacts can function as mediating tools. *Perezhivanie* then stresses how the cultural context determines how people signify their experiences. Research mostly influenced by this theoretical perspective describes what effect cultural representations have on individuals' experiences. No educational research was found within this perspective; instead, experiences, such as death, have been explored. For example, different cultures' representations of death can affect the emotional content of that experience. The difference between "my mother doesn't exist anymore and I will never see her again," or "my mother is now in heaven and is observing me" can have substantially different emotional outcomes for the individual [31,44]. Fields which are explored in this analysis are emotion regulation and special education.

4.1.3. Research within the Individual Perspective: Perezhivanie as an Inner Production

In the subjective perspective, the notion of social environment is abandoned, and *perezhivanie* is seen as an inner production, a creation based on subjective senses and configurations [33,34,45]. *Perezhivanie* is seen as varying "depending on which characteristics of personality are at play in the given situation" [46]. The subjective senses used in each situation define the content of perezhivanie. Research within this perspective acknowledges that a person exhibits a tendency of interpreting different things in a similar manner. In other words, subjective senses express themselves in patterns. These patterns of making sense are called subjective configurations. Within this theoretical perspective, *perezhivanie* is seen strictly as an individual phenomenon, which cannot be generalised to other individuals. An individual experience cannot be attributed to other people. A representative example of this kind of research appears in the field of early childhood education [47], in which researchers explored how a pacifier becomes an artifact of interchanging meanings between different actors. The pacifier becomes a sign of posessivity, discipline or a form of teaching social interaction. This interchange was the product of the specific circumstances and the individual meanings which were at play.

4.2. Intervention-Based Research Papers

4.2.1. Research within the Social Perspective: Play as a Motivational Environment/ Pedagogical Instrument

Researchers influenced by the social perspective apply *perezhivanie* in experimental research as a pedagogical instrument. Here, the researcher's goal is to create a situation that will become a significant experience or dramatic event for the learner. Scientific play-worlds is one example of a pedagogical method that focuses on children's interests and emotional connections [23]. The methodology of scientific play-worlds has been used for the purpose of teaching engineering and STEM in preschools [24–26,48] as well as for the adult population. Results show that the method has successfully been applied to change an individual's stance towards science [49] and to develop executive functions [50,51] and science concepts [14].

4.2.2. Research within the Cultural and the Individual Perspectives: Drama as a Method for Exploring Modes of Experiencing

Similar to research derived from the social perspective, research derived from the sociocultural and subjective perspectives used *perezhivanie* to develop pedagogical methods for educational purposes. Drama or "fantasy-based struggles" [52] or fairy tales [53] are two of the methods developed for including emotional experiences. The goal of these methods is not to explore subject-specific knowledge, but instead to promote or cultivate self-reliance and self-confidence [27]. Topics such as fear, security, loneliness, racism, marginalisation and the feeling of being worthless or denied are common [28,54]. Conflicts are embedded inside the storyline, and the method supports children in experiencing the unknown in a secure, fictional environment. This perspective also includes research on disorders within the autistic-spectra, where research following similar methodology supported children in their exploration of the environment without having emotional crises [55].

4.2.3. Research within the Individual Perspective: Cultivating Self-Awareness

The present analysis identified a distinct group of experimental research inspired for the most part by the individual perspective. Similar to the other perspectives, *perezhivanie* relates to an emotional experience that provokes new ways of thinking about a situation [8,56]. Reworking emotional experience is one approach used for overcoming a traumatic experience. Researchers, inspired by this aspect of *perezhivanie*, attempt to operationalise it in concrete experiments in the form of cultivating self-awareness abilities. In the educational context, research results show that it would be valuable for children, educators, and adults to receive training for developing their self-reflection processes. Reflective journals [57,58], collaborative forums [59,60] or group writing conferences [61] are methods suggested to help teachers in their self-reflection [62,63].

In research focused on children, methods like drawing self-portraits [64] and using avatars [65] have been found to contribute to children's emotional regulation [31,66,67]. This line of research has the goal of helping teachers "know their students as complex, creative, and competent individuals with pasts and futures" [35,68]. Children's subjectivity is also explored here through the use of avatars [65] with the aim to develop self-understanding, identity [64] and emotional control [67].

As *perezhivanie* is connected to learning and development, much of the research conducted comes from early years learning. An analysis of the results derived from this research is important for understanding the contemporary use of the concept.

4.3. Early Childhood Education Papers

The content covered within the 22 articles related to early childhood research was analysed to explore what specific aspects *perezhivanie* contributes, especially to research in early years education. In general, the concept has provided early years education with means to explore children's individual, emotional interpretations of events and to focus on the emotional contribution to development. Secondly, it has been used for deriving educational methods. The first category, that of development, includes the development of executive functions (Ef) [51], social relations [69] during the transition between educational levels [39,69,70] or cultural transitions [36,39,42], emotional regulation [41], teachers' professional development [20,59,63,71] and the development of scientific concepts [40,72].

The second category of research involves educational methods for creating meaningful learning situations [55], a category that focuses on contextualised learning situations for creating common meanings [47] and positive emotional involvement from groups of children through the use of fairy tales [19], games [73], play-worlds [73], and role play [55]. Using *perezhivanie* as the unit of analysis does indeed provide a fine-grained level of analysis, which when applied to early years education can help educators to support the development of emotional regulation and positive attitudes toward different topics. Some of these results are described in the following sections.

4.3.1. Development of Executive Functions

Results show the use of play-worlds and the teacher's role for developing children's executive functions (Ef). Executive functions include working memory, inhibitory control and cognitive flexibility, aspects that are seen as essential for school readiness. Play-worlds are here suggested as important frameworks for the development of Efs in particular, since discussions of the events in the play-world provide means for children to think deliberately of their role and to make plans. Research has shown that in the context of imaginary play, children trained their working memory as they were capable of adopting new game rules as a result of the roles they undertook. Similar results were facilitated with the ability to inhibit and self-regulate [51]. Imaginary play also allows teachers to embed problems and extended discussions make the children remember plots/roles and rules [73], all of which support the development of Efs.

4.3.2. Development through Social Relations

A series of different studies have been performed, and analysis of play-dates shows the importance of both individual and collective aspects of social interactions. Supporting individual children to learn social roles like taking turns and waiting for each other is important, since the individual affects the collective and the collective the individual. The inclusion of the child into planning play-dates gives agency to the child and provides them opportunities to discuss both the content and social interactions within the play-date. Other studies have shown that children as young as toddlers interact with familiar objects, such as pacifiers, and create shared meaning through imitations of movements and gestures [47].

4.3.3. Development through Cultural Transitions

Children in either transitions between educational levels or transitions between countries may experience emotional crisis that can bring about development. Events like unpacking familiar toys in a new country have been studied, and results show that the event may be a positive experience for one child as the old toys may hold symbolic meaning for the child, while for another child familiar things in a new environment produces a more negative emotional crisis [42]. Research concerning bi-cultural transitions to school does indeed emphasise the subjective interpretations by showing how children from the same culture have different emotional and cultural experiences as well as cognitive understandings. Results show that subjective analysis is important to support the individuals' transitions better [36,70] and that every transition is unique from the child's perspective [69]. Transitions especially signify potential crisis, and crisis handled the wrong way can be harmful for learning and development [69].

4.3.4. Development through Professional Development

Here, emotional aspects of early years teachers were studied for several reasons. Emotional investments are important for early years educators, when at the same time personal feelings are difficult to combine with their professional role [63]. An approach for development of pedagogical practices that includes emotional aspects has been suggested. The approach involves collaborative forums where teachers video-record and together with other teachers analyse their communication; one result from this study was the importance of communicating with the children on their level [59]. Also, teachers' own experiences of their workplaces have been explored through the concept of wellness, and results show that this concept for the teachers is a combination of physical, cognitive, psychological and emotional aspects, as well as a balance between demands and resources [20].

4.3.5. Emotional Development

In early years education, much focus is placed on emotional development within this field of research and has been performed to explore parents' contribution to children's emotional development. Results show that parents' awareness of their emotional responses (affect in intellect), such as parents' awareness of their own anger, is an important aspect for emotional regulation, something that helps to support children's emotional development and shows the collective nature of the subject and the environment [41].

4.3.6. Developing Educational Methods

Results show the importance of the subjective aspects in learning experiences by revealing how role play created emotional experiences for one child and also provided an entry into the social world [55]. Other research projects use *perezhivanie* for designing emotionally connected learning situations; here, positive emotions are analysed through gestures and verbal expressions as well as body language. Results show that adults are keener to participate in games than play and that games can help change people's attitudes [34]. Other emotionally connected learning situations can involve creating environments of co-experiencing, where emotions like sadness or joy can be discussed and generalised through the use of fairy tales [39].

4.3.7. Developing Scientific Concepts

Results show children's personal descriptions of what is included in the concepts of clouds, where the starting point was metaphysical interpretations of divine intervention. With help, this description progressed toward the inclusion of sky and air and dust, and then further toward the inclusion of rain, drizzle and rainbows. Detailed analysis provides more and improved dynamic support for young children's learning and development [40].

5. Discussion

5.1. Contributions of Perezhivanie to Contemporary Research in General

There are two general aspects of *perezhivanie* that appear in the literature: (a) *perezhivanie* is used for understanding differences in what we focus on and how this event is interpreted, and (b) *perezhivanie* itself is changed by intentionally creating emotionally connected experiences. Indeed, *perezhivanie* is used in connection to learning, seen as a change, within all articles. The difference between the different theoretical perspectives in the operationalisation of *perezhivanie* provides means for focusing on various aspects, such as changes in social relations, changes by cultural mediations, or changes in the individual.

Research influenced by the social perspective situates *perezhivanie* within the context of social dynamics and places focus on social positioning or the development of pedagogical methods intentionally designed to create positive experiences of learning [24,25,28]. Here, the concept of *perezhivanie* provides a logic for intentionally affecting learning over a lifetime.

The sociocultural and subjective perspectives are sources of inspiration for experimental research, which lead to the result that the significance of *perezhivanie* was not to identify an experience, but rather to train all relevant actors in the educational context to be self-aware of their *perezhivanie* processes [59,61]. This line of research blurs the border between education and psychology, in the sense that it suggests that teachers and students should learn methods for self-exploration. The learning in focus here is emotional exploration, which may help in facing the challenges that education in general poses nowadays.

5.2. Perezhivanie in Research Concerning Early Childhood Education

Perezhivanie can be considered as a theoretical concept that allows the study of a broad array of aspects surrounding the child's development in general and science education in particular. It is a concept that re-establishes a connection between early years education and psychology, building a bridge between the two disciplines. This connection raises a series of questions regarding emotional and professional care, as well as questions regarding emotional development in general.

The concept has indeed become an important analytical tool to apply in early childhood research. The diversity of perspectives shows that the scientific community is still making progress toward understanding the notion of *perezhivanie* and experience. Considering this discussion with regard to early childhood education, the concept of *perezhivanie* is opening up a wide variety of research questions and problems [43]. There is extensive growth especially in early childhood education, signifying a turn towards processes of individual learning and subjectivity [47].

5.3. Limitations to the Study

By limiting the literature search to Web of Science, important contributions to current research may have been overlooked. The results may also have been affected by the fact that the categorisations were based on only two independent analyses.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/educsci11120813/s1. Table S1: Raw Data Table.

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Article

Preschool Children's Reasoning about Sound from an Inferential-Representational Approach

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Abstract: The purpose of this article is to present an analysis to identify the reasoning processes and representations that preschool students develop about sound based on the inferential-representational approach. Participants were 18 preschool students between the ages of four and five attending three rural schools located in the Sierra Norte of Puebla, Mexico. Data were obtained through a 14 question semi-structured interview. From children's answers to the formulated questions, an inferential analysis method was applied to identify intentionality, representation elements, sign-material expressions, representations, inferences, and coordination rules in students' constructions. The results show that children build a basic set of epistemic tools to give meaning to their interpretations and can use them as surrogate reasoning to make inferences. This research constitutes the first approximation toward the understanding of preschool children's reasoning forms with an inferential-representational approach and constitutes a new approach that puts forward new referents to analyze students of different ages. We consider that the described results and analysis have implications on science education at this educational level.

Keywords: preschool; representations; science education; epistemology

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1. Introduction

The benefits of including science in preschool classrooms are undeniable. The analysis of how students build their representations is still a fundamental question because it allows us to comprehend how we build physical understanding and give meaning to our surroundings. This knowledge lets us build effective strategies that improve teaching and learning processes in the classroom. The ideas that students develop have been the subject of analysis for several decades. Researchers have covered the fields of physics, chemistry, and biology at all educational levels; however, research in children under eight years old has been infrequent, especially in the field of physics [1].

An example of this is the study of sound ideas. Most works over this topic analyze ideas from high school and college students [2,3] and only a small set of works are focused on children under eight years [4–10]. Table 1 presents a synthesis of some reported works.

The studies described in Table 1 show that students' ideas about sound do not allow them to understand diverse situations in which sound is present in their daily lives. On the other hand, although it is important to understand children's ideas and conceptions, previous research does not contemplate how such ideas are developed, the required steps and reasoning processes.

Research questions: How do children build their representations about sound? What is their reasoning process? Is there a set of a basic nucleus in which they base their inferences? To answer these questions, the objective of this study is to identify the reasoning processes and representations that students develop about sound at a preschool level using as a tool the inferential-representational approach analysis to answer these questions.

Table 1. Synthesis of research papers of students' ideas about sound.

Authors	Ages	Ideas about Sound
Piaget (1973)	4–5 5–6 7–10 11–15	Sound is something that remains in its place. Sound is something that comes out of an object toward the ear and returns to the object. Sound moves in a straight line in all directions. Sound expands and travels through the air.
Driver, Squires, Ruschworth and Wood-Robinson (1994)	4–16	Sound is produced by the actions that subjects make over objects. Sound is a part of objects. Sound travels through the air.
Mazens and Lautrey (2003)	6–10	Sound cannot pass through solid matter. Sound passes through materials (if they have holes). Sound passes through materials that are not too strong. Sound is associated with the idea of vibration.
Eshach and Schwartz (2006)	13–14	Sound has substantial characteristics. Sound can push another object. Sound can be contained inside an object. Sound can be added to another sound.
Sözen and Bolat (2011)	Basic education	Sound travels through vibration and causes particles to move. Sound is heard through vibration and matter.
Delete for review (2018)	5–6	Sound has object properties. Sound is related to vibrations, but it is not possible to explain further.
Delete for review (2019)	4–6	Sound is within objects. Sound depends on a subject's actions and can be perceived because we have ears. Sound bounces in materials. Sound requires space to propagate.

2. Representation and Reasoning: Basic Assumptions

The present paper focuses on analyzing representations that preschool children build about sound from an inferential-representational approach. This method allows us to analyze representations as epistemic entities that, through their constitutive elements, take subjects to the elaboration of inferences through a surrogate reasoning process that will lead to the construction of the best possible explanation (pleasing for the subject).

Before describing the inferential-representational approach and its implications on the analysis of children's representations, it is convenient to establish some preceding aspects necessary to determine the representations' function and children's reasoning process.

Origin and Function of Representations

The analysis of representations has been managed from the epistemological and cognitive approaches. In the epistemological approximations, the representations are related to the possibilities of the subject's interaction with the environment. For Wartofsky [11], the representations are the perception medium that is determined by the action with objects, transforming it into a "virtual action" [11] (p. 194). This basic idea that contemplates that action transforms interaction (action-perception) is present in many of the philosophy representatives [12–14]. The representation is a basic interaction element (possible action, interpretation, and intention) with the phenomenal surrounding.

The representation's epistemological conception coincides with the perspectives of the cognitive analysis. The proposals from this perspective start from initial construction, determined by the body's capabilities over the world [15]. This process has been referred to as "embodiment" [16,17]. These representations are not an image derived from a performed action. They are an element of interpretation and interaction in which aspects such as perception, intention, and goals are involved [16,18]. These aspects make representations to characterize them as a structure or an internal mind system.

Burr and Jones [19] present this position in the following way: "How does a system such the brain manage to use its sensory input to represent the states of affairs in the world [emphasis added]". The brain achieves this by utilizing active sensorimotor predictions, which have high reliability, to represent the world in an action-oriented manner" [19] (p. 597).

The original and primary function of representations is to take action within a subject's environment to conserve their existence; however, as representations move to a more abstract plane (graphic and symbolic object), the finality of the representation goes beyond the conservation of existence and transforms into an intervention with diverse intentionality. Additional to this action-intervention function, the representation has an extensional function in which it can be translated to other contexts or situations beyond the ones that originated the representation, amplifying the possibilities of intervention. Therefore, the intervention in the world also implies a change of it: "But beyond this, perceptual activity is now also shaped to, and helps to shape a new and different world, namely that world which is a cognitive construction, and is embodied in our representation, as theories and models in science, and as pictures in art" [11] (p. 195).

3. Embodiment's Role in Preschool Children's Reasoning

Although the construction of representations, which implies a mind–body relation, is a process that takes place in multiple situations [15], it can be considered that in a subject's development a basic or nuclear set is built from the representations that constitute an axiomatic base to interpret and develop actions and inferences over a wide variety of situations from a phenomenon or problem presented by others. In other words, they are a set of resources that act as restrictive and corporal action elements from an interpretation of a real or imagined situation of the environment [20].

There are many conceptualizations about embodiment, and in this paper, we consider the conception of embodiment-cognition as: "Cognition is best explained in terms of embodied representational states that utilize the same mental resources as are involved in perception and the guidance of action" [19] (p. 589). Based on the last section, we can say that representations generated through the process of embodiment (embodiment-representations) constitute basic structures of the cognitive system that allow the subject, willingly, to interpret and act upon his or her surroundings. Under this idea, it is possible to think that preschool children's constructions about an explanation of certain phenomena or problems about daily physical aspects, such as sound, are constructed from a set of basic representations built over their development. This aspect is one of the assumptions of the present research.

4. Children's Reasoning

One of the changes in our way of conceiving children's reasoning has to do with the idea that cognition is the result of active manipulation, and therefore, action influences over perception, indicating that perception and action are inseparable [10,21,22]. When children are active participants, it is possible to observe more complex reasoning and understanding that are not necessarily expressed verbally, but rather through other resources such as gestures or the combination of gestures and tools [23,24].

One of the opinions we share with Sherin Krakowski y Lee [25] is that students build their reasoning, and therefore, their explanations when they intend to answer questionings; this has also been expressed in the Possible Partial Models [26] where students construct their reasoning based on a set of constricting and corresponding ideas that come from previous cognitive resources.

These reasoning processes can be more or less sophisticated depending on the function of the elements presented as objects, other representations, and the contextual conditions of the questions [27–31]. On this topic, previous conceptions and knowledge domains also have to be considered, given that they have an essential role in the possibilities of scientific reasoning [32,33]. A good example of how preschool children can integrate previous conceptions in their reasoning process to solve new situations is presented by Hast [34]. The study of inferences developed around curved and inclined movement in which previous conceptualizations about free fall and horizontal movement are integrated.

There is still much to analyze from the processes of reasoning, as expressed by Sherin Krakowski y Lee: "We need a better understanding of student reasoning processes in the circumstances we study; we must understand and model students reasoning as it occurs in the interview, we employ to study commonsense science" [25] (p. 169). Through this paper, we echo the necessity of developing complementary elements to previous works to find new aspects for the comprehension of the reasoning and representation processes. We focus on the perspective of inferential construction of representations, taking as a starting point the recent development on the science's epistemology. This approach represents a new proposal of analysis of the construction of representations and reasoning, providing new elements to understand the comprehension of physical processes in students and give answers to research-oriented questions.

5. The Inferential-Representational Approach

This paper adopts the inferential approach of representations [35] because, in comparison to the structural approach, it presents the following advantages: (a) it does not establish any type of similarity requirement between the represented and the representation; therefore, it does not require symmetries between the represented phenomena and the form of representation making no assumption of the catchment of reality or part of it; (b) it solves the problem of not having the necessity to demonstrate the symmetry, reflexivity and transitivity processes that Suárez [35,36] has demonstrated that the structuralist vision cannot solve; (c) it enables the understanding of representations as fictitious entities; (d) the construction or interpretation of representations depends on the elements that the subject has to carry out a surrogate reasoning from representation denotation elements.

The inferential approach can be characterized by factors such as intentionality (referring to the subject's awareness of the purpose or finality of their representation). Interpretation implies recognizing elements that give meaning to the representation, and surrogate reasoning is based on the representation elements to create a hypothesis or explanation that can be applied to what is intended to be represented [35,37,38].

It is important to emphasize that, in this approach, the established representations (by the subject or others) constitute a tool or epistemic artefact, referring to an intentionally built entity materialized through some medium (object, image, or expressed symbol) and used in multiple ways [30–41]. The epistemic tool implies that a subject can build new representations whose level of functionality will be determined merely by the form of expression and by the possibilities given by the theoretical, empiric, and contextual elements that the subject provides.

6. The Inferential Approach as an Analytic Tool

With the use of the inferential approach in analytic terms to establish the children's reasoning processes, it is necessary to define the elements in such representations. From a general framework, we propose that representations must comply with the following:

Intentionality (what is intended to be represented). Every representation intends to represent some part of a directed process toward an end or main goal. As pointed out by some authors [42], even six-month-old children are capable of conceptualizing the intentional state agents that have an orientation toward a final goal.

Forms of expression (sign-material). This implies that every representation has a form and material to be expressed. Images, language, charts, objects, among others, determine different reasoning constrictions of the representation provided elements, allowing the combination or ensemble of different forms of representation with different purposes. The representation of an object's movement in some direction is an example of expression forms.

Interpretation, referring to the implication or meaning of the representation. Every subject establishes an interpretation that attributes a function and meaning to the elements of their interpretation. The previous example has the elements of a vehicle and an arrow, and each element represents an entity; for example, the drawing represents a specific vehicle, and the arrow represents an action (movement) and direction (orientation). The representation of movement only acquires meaning when the element of an arrow is applied to the vehicle representation (by itself, the arrow could have other meanings, such as strength).

Inferentiality, referring to the surrogate reasoning that allows inferences. The representation elements are used to reason with them, resulting in an inference when applied to real or imaginary objects. In the previous example, a subject can infer the movement direction (left or right), the vehicle speed, or if an element will catch the other.

Rules of coordination. They show how the inferred elements of the representation connect with the represented. The verification of inferences requires the construction of procedures to estimate if they are correct or closer to be correct, such as measuring and observing the phenomena. For example, they measure the vehicle speed.

In synthesis, the representation characteristics are based on the subject's ability to establish every function and characteristic of the representation. Such elements will enhance the subject to build knowledge and explanations in a specific context. Without such context, the representation would not have a way to be used as an epistemic tool [43].

7. Materials and Methods

7.1. Method of Analysis

Based on the inferential conception framework and the representational construction process, we analyze children's reasoning, explanations, and sound representation. Participants' age is between four and five years old and is between the second and third grade of preschool.

7.2. Representations as an Epistemic Tool

The representation is developed as an epistemic tool by children. The construction of the representation requires observing and recognizing the elements of the phenomenon through its processes of everyday experience and embodiment. With the elaborated representation, it is possible to establish inferences through a surrogated process of reasoning. In a correlative manner, the construction of representations will be constituted by its elements derived from previous conceptions that establish their cognitive resources. These resources are mainly determined by the basic conceptions derived from the embodiment and experiences that are recovered during the elaboration of inferences and representations.

Based on children's explanations and inferences, it is necessary to determine the reasoning process and the construction representations. Table 2 synthesizes the proposed method of analysis to determine the representations and inferences from students and shows some examples of students' answers.

Every subject will build their epistemic tool based on the described elements, performing an inferential process. Therefore, every interview from this procedure will be analyzed.

From previous research on children about the topic of sound, see Table 1, it can be foreseen that the representational diversity will be bounded to common elements established by the process of embodiment in preschool children. Based on this assumption, possible sets of representations and similar inferences will be established to determine everyday patterns.

7.3. Sample

The present research worked with a no probabilistic intentional sample of 18 children attending preschool between four (four boys, five girls) and five (two boys, seven girls). Children were preschool students from three rural schools located in the Sierra Norte of Puebla, Mexico. The schools had a low socioeconomic level. In Mexico, preschool is the first basic education level and is formed by three school grades. The students from our sample belong to the second and third grade. They take classes together in the same classroom with the same teacher and participate in the same school activities.

Table 2. Factors and the way to determine them based on children's expressions.

Factor to Determine from Representations	Determination Process
I. Intentionality	Questions and answers aligning. Example: "How you can produce sound?" If I hit with a stick
II. Elements of interpretation: (a). Embodiment-base ideas (b). Daily experience	Direct expressions of a process perception and involved organs in the perception. Example: "It can be hear because you have ears." Expression that refers to some type of observation, self-observation or from others. Example: "The strong sound can be heard even with the ears covered."
III. Sign-materials expressions	Constricted expressions from drawings and objects. Example: "The sound stays in the hose."
IV. Representation	Representation elements' integration. Example: "The sound travel in the air."
V. Inferences	Expressions that indicate a supposition or explanation. Example: "If something is covered with a box then the sound is trapped."
VI. Rules of coordination	Expressions of corroboration. Example: "The sound bounces off the hose because I don't hear it anymore."

7.4. Instrument and Materials

A 14 question semi-structured interview was used. The interview considers three basic topics of sound: the first one refers to how sound is produced; the second topic refers to how sound is perceived; the third topic refers to how sound propagates. The interview was semi-structured, and the questions were conducted in three sections: (a) questions about sound production about their experience (objects from the surrounding and materials, specifically designed for the interview, such as drawings of animals, insects, objects, among others); (b) questions about hypothetical situations (cover the head with a box); (c) questions about experimental situations (marimba formed by three keys, each one from a different material, e.g., metal, rubber and wood, a hose telephone, and a musical triangle that was tied to a couple of earmuffs). Figure 1 shows some of the objects and photos used during the interview.

7.5. Procedure

Every interview was applied individually with an approximate duration of 30 min. During the interview, a member of the research group participated, and a cameraman was present. The children's teacher was present as an observer. Every interview had the consent of the children's parents, teachers, and the schools' principal. All interviews were transcribed and analyzed based on the presented framework.

Three researchers analyzed the children's responses in the interviews, two of them specialists in science education and physics, the third being a specialist in science education and cognitive pedagogy. The researchers had a 90% agreement and the difference was resolved by consensus.

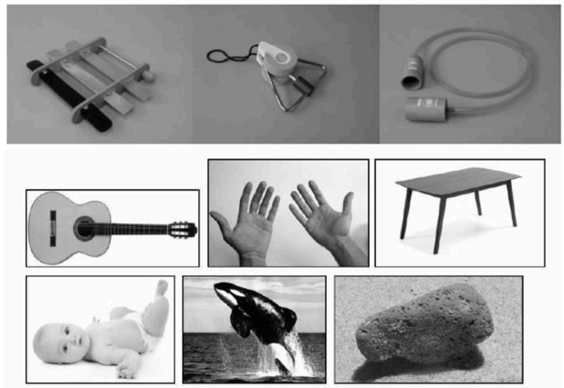

Figure 1. Images and instruments used during interviews.

7.6. Categorisation

The interviews were transcribed in their totality. An inferential analysis method was applied to the interview transcription from children's answers to the formulated questions. The elements of characterization proposed in the methodology of analysis were identified by the researchers' consensus.

8. Results and Analysis

We present the results of every representation factor and reasoning process determined by applying the inferential method.

Intentionality. Eleven children give answers that are aligned to the questions, and they recognize what is being asked about sound and its possibilities of being produced or heard, establishing their representation construction process. Some examples of the answers are: "If I hit with a stick, I can produce a sound", "If you blow it you can produce a sound (trumpet)", "You can listen to it because you have ears", "I speak aloud so he listens because he is on the other side of the school". Seven children seem to confuse the intentionality of the question at the beginning of the interview; therefore, their reasoning is oriented toward communication possibilities. For this case, some examples of students' answers are: "animals do not listen, only if they are from the same species" or "He does not listen because I call him and does not comes". Only one student does not establish any recognition of intentionality, giving diverse answers or is limited to saying, "I don't know".

Elements of interpretation. Throughout the interview, from their elements of embodiment and daily experiences, children assemble the elements that will bring structure to their representation. The directed derived conceptions from the embodiment processes are conceptions derived from the recognition of perception through the ear and the direct action that comes from children's daily experience. These conceptions have been used since the early stages of development. From this condition, children recognized the intentionality of the question and developed expressions that account for their experience through perception–action processes [15,19]. Some of the central or basic elements that preschool children present are the following:

Embodiment-based idea 1 (Emb1). Sound is perceived through the ear, i.e., "It can be heard because you have ears" (100% of the sample).

(Emb2). Sound is produced by an action, i.e., "The sound is produced when you hit the table", "When I speak" (100% of the sample).

(Emb3). More intense sounds (strong) require a major or stronger action, i.e., "If you cover the ears, the sound is strong if you can hear it", "The strong sound can be heard even with the ears covered", "If someone is from afar you have to speak louder so her or she can listen to you" (100% of the sample).

(Emb4). Sound is a substantial or material entity. In diverse ways, children express that sound has material properties; for example, expressions such as "If something is covered, like a box, the sound gets trapped and cannot be heard outside" (two five-year-old girls and one five-year-old boy, one four-year-old girl), "Sound weights and can bring down a tree" (one five-year-old boy).

(Emb5). To continually produce a sound, it is required to maintain an action, i.e., "If you stop hitting a key (from the marimba) or a box, the sound stops", "The sound must be repeated several times so it can be heard, if not it will be lost" (one five-year-old girl).

(Emb6). If there is a space for the sound to pass through, it will be heard. Some representative expressions are: "Sound comes out from everywhere in the box, that's why it can be heard" (one five-year-old child), "Sound passes through the little hole in the hose" (two four-year-old girls and one four-year-old boy, and one five-year-old boy).

Along with these expressions, children establish others that are derived from the observation of others' actions. For example, to recognize that musical instruments produce a sound requires the pulling of chords of a guitar ("stretch") or blowing the trumpet to make a sound. Some other experiences have a mediated interpretation and do not have an immediate recognition as an experience; for example, the notion that different materials produced different sounds. It can be found in an expression such as: "The iron sounds loud", "Metals have strong sound" (one five-year-old girl and one five-year-old boy, one four-year-old boy), "Wood does not produce any sound" (one four-year-old boy and one four-year-old girl).

Sign-materials expressions. These expressions appear in the questions and materials used toward this goal, such as instrument illustrations, animals, objects, and experimental activities such as a hose phone, a triangle with a thread, and earmuffs (see Figure 1). The interpretation that children make with these elements will complete their epistemic tool representation, allowing them to develop their inferences.

Rules of coordination. As previously expressed, these rules have a function to relate the inferences with the real phenomenon; therefore, they are oriented toward proving, which in the case of explanations and predictions in science are usually constituted by measurements and experiments. In the case of young children, we can expect a direct proving such as the affirmation of their explanations by referring to the perceived or observed event. In this case, children express their affirmations by making short expressions such as: "It can be heard", "The sound does not come out", "Yes, the sound is strong", among others.

As it can be appreciated, there is a set of elements where children have to establish a representation of the sound that allows them to infer explanations or possible situations. In the case of specific questions that pose a condition where sign-material elements are present, children build the best possible explanation. For example, one of the activities children did in school was to talk through their hose telephone. A fragment of the following interview illustrates the previously mentioned idea:

I = Interviewer; S1 = student (five years old)

I. Can you listen to the person on the other side of the hose telephone?

S1. Yes, I can.

I. How do you think that sound can reach there?

S1. The noise goes from this tiny hole that you have here until it reaches here. [pointing to the interior of the hose and the sound trajectory]

I. What happened to the sound of my voice? How does it got where you are?

S1. Because it goes like this. [pointing the hose from the middle up to where she is]

I. And what would happen if I fold and squeeze the hose? What will happen when I speak to you again?

A1. I would not listen.

I. You would not listen, why?

S1. Because you are covering it like this, so the noise gets stuck in there, and it will remain there. I cannot hear it.

The previous example shows: how the sound is interpreted as a material or substantial entity (Emb4); how the sound is produced by an action (Emb2); and the notion that sound travels in space (Emb6). These elements assemble with the conditions or sign-materials' expressions of the activity. In this case, the activity consists of two people listening on the opposite sides of a hose telephone. Based on this, the surrogate reasoning and inferences can be constructed as follows:

Sound is a material entity that requires space (hose hole) to travel through and be listened to; if the space is interrupted (folding or squeezing the hose), the sound will not be able to pass through and will be trapped.

To give certainty to the inference, the coordination rule that subject S1 uses is her direct observation on the folded hose and the corroboration that she is not listening through the hose anymore.

From the reasoning process previously shown, it can be noted that the representation used by subject S1 is used as an epistemic tool to elaborate her reasoning that can be summarized as: "The sound is a substantial entity that requires a space to travel". With this reasoning reconstruction process, applied to all participants, the sound representations shown in Table 3 were found.

Table 3. Preschool children's sound representations that function as an epistemic tool (T#).

Epistemic Tools	
T1	Sound is a substantial entity that can be perceived through the ear.
T2	Sound is in objects (people) and can be produced by action from them.
T3	Sound is a substantial entity that requires a space to travel.
T4	Sound is produced and transmitted differently depending on the materials.
T5	For a sound to last long, the action that produces it must be repeated.

These small representations, contextual conditions, and established sign-materials are established for children to solve their situation through reasoning. This allows us to explain how epistemic tools are used and if they can explain children's answers.

In the next section, two examples of different reasoning complexities will be presented.

Example 1. During the interview, a series of drawings (shown in Figure 1) are presented to a four-year-old boy (subject A2).

I = interviewer, S2 = student (four years old)

I. I am going to show you some drawings or photos and you're going to tell me if we can make sound with them (referring to the content of the drawing or photo)

S2. Nod his head.

I. What is this? [showing the card]

S2. A guitar.

I. What could we do with it to make a sound?

S2. Playing it.

I. How would you play it? If the guitar were real, which part would you touch to make a sound?

S2. Stretching the threads.

...

I. What is this? [showing a card with the drawing of a spider]

S2. A spider.

I. Do you think a spider can hear?

S2. No, she only catches bees or some little worm that flies toward his web.

In this case, animal drawings (whale and spider) do not show any indication of an auditive system in those animals, prompting children to establish direct inferences such as:

Ears are required to listen (T1) because the animal or object (chicken, whale, stone) does not have ears (sign-material condition) in the graphic representations, and thus those entities cannot hear. The lack of ear identification implies that children express other actions that the organisms can perform, as seen in the spider's case.

A more elaborate case of reasoning is presented in example 2.

Example 2. During the interview, a musical triangle is presented (see Figure 1). The instrument is hanging from two strings that are tied to earmuffs. The triangle is played with a ramrod and heard by the student. Before the action, the student is asked:

I = Interviewer; S3 = Student (five-year-old girl)

I. If you put the earmuffs in your ears and I play the triangle, do you think you could listen to the sound?

S3. No.

I. No, why?

S3. Because the ears are covered while you play and after you take them off and you play again you will listen.

I. If I take off the earmuffs and play it again, I will listen, but if you have the earmuffs on with the ears covered you do not listen.

I. Do we try it?

S3. [student nods with her head]

I. Lean a little bit, so the triangle is not close to your body, okay now I am going to play. What happened?

S3. I listen to the sound. Because you play it, and the sound went like this. [The student points to the triangle and then points to the string that holds it]

I. Oh, because I play it, you think the sound went like this, how did it move?

S3. Through the strings

I. Through the strings. Where did the sound travel?

S3. Up to the ears, it went to my ears

I. It went to the earmuffs and then to your ears. Why do you listen to it when it reaches your ears?

S3. They must have holes. [referring to the earmuffs]

In this case, the devices such as the earmuffs or the strings that hold the triangle act as constrictions of the child's representation. The perceived sign-material elements couple with the epistemic tools. In this case, the student's reasoning can be built into two parts:

r1. Sound is a substantial entity and is perceived by the ear (T1); if I cover my ears, it cannot be heard.

This inference is not fulfilled because the student's coordination element does not occur (not listening to the sound) because she listens to the sound while wearing the earmuffs; this leads to the introduction of new elements—some of them are determined by the material but others are superimposed to the material to satisfy the premise.

r2. The sound is produced and transmitted through different materials (T4), the sound travels through the string up to the earmuffs. As the sound is a substantial entity that can be perceived through the ears (T1) and the sound is a substantial entity that requires a space to travel or move (T3), it must travel through a space that can only happen if the material has space (little holes).

As it can be seen, the epistemic tools that guide the reasoning processes when the expected rules of coordination are not met reinterpret the sign-material conditions, forcing the epistemic tool's function to obtain the best possible explanation, which in this case is translated to a porosity attribute (not observed) in the material. This reasoning that belongs to a five-year-old girl shows us the processes of assembling sound representations as epistemic tools to build complex reasonings to interpret and explain complex phenomena, given that the notions of medium vibrations and their perception as sounds are not yet built by children from those ages and even older children, as shown in previous research about the topic (see Table 1).

9. Conclusions

The present study considered the elements of intentionality, representation elements, sign-material expressions, representations, inferences, and coordination rules as elements that characterize preschool children's representation of sound. From the results we can highlight the following aspects:

Children build a basic set of epistemic tools to give meaning to their interpretations and can use them as surrogate reasoning to make inferences.

The student's reasoning complexity depends on the sign-material elements that are present during the inquiries. Some questions implicate a direct or straightforward inference where a representation with an affirmative (perceived ears within the drawing) or adverse condition (perceived absence of ears within the drawing) leads to a direct inference. On the other hand, when there are situations that do not correspond to the student's inferences and the rule of coordination is not confirmed, more representations are assembled (epistemic tools) with the sign-materials aspects. This process took place in the experimental activity cases, where more elements constrict the inferential possibilities. Two of the most relevant examples occur in the reasoning cases around the hose phone and the triangle with the earmuffs.

The basic set of representations that work as epistemic tools (Table 3) also appear in previous research over other populations and environments in children within the same age range or older (up to 10–12 years), indicating that this basic set of tools endures through children's development and continues the generation of the same type of ideas, hypothesis, and conceptions, at least in the case of sound [4–6,8–10].

Based on the inferential conception of representations, the analysis proposal constitutes a new approach that comes from the philosophy of science and puts forward new referents to analyze the construction of representations and reasoning processes from individuals of different ages. This approach is applied to the established scientific knowledge in the disciplines and any interaction with the phenomena, involving the interpretation and explanations people create, including preschool-grade children.

As this approach does not demand a similarity between the representation and what is represented (what is real), it can be applied to any representations that children make in the embodiment processes. Although the representations correspond with daily constructions and common sense, they do not correspond with scientific representations.

When children construct their explanations of how sound is heard, how it generates and how it propagates, they employ the acquired knowledge of previous experiences; for example, what they had heard or what they are looking at the moment, such as the use of images during interviews or specific situations as in using the hose phone. These children's explanations show that their representation involves the brain, the body, the context, and the interactions with these elements. The exposed examples demonstrate that preschool children's expressed constructions are not packages of information and definitions, but dynamic representations that come from a cognitive–sensorimotor interaction.

We consider that the described results and analysis have implications on science education at this educational level. On one hand, it provides clarity over children's reasoning and how they construct the knowledge of their physical surroundings, including sound. On the other, it brings elements for the design of activities used in the classroom's educational process, based on a basic set of representations. The generated representations at this stage have an important implication over posterior learnings. Many of these have a substantial change resistance given that they enhance adequate reasonings to explain children's surroundings. The described results have utility toward the improvement of the design of external representations, for example, the drawings and images of schoolbooks. These external representations provide epistemic tools for children to reason and interpret their classroom activities.

This research constitutes the first approximation toward the understanding of preschool children's forms of reasoning with an inferential-representational approach. There is much more to inquire and new research lines to be opened to understand how abstract concepts are built, which, at first glance, do not seem to have a perceptual correlation. Future steps could be centered on exploring the possibilities of inferential analysis to explain students' reasoning in other knowledge domains and different cultural settings.

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Article

Psychosocial Obstacles in Young Children Argumentative Interactions

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Abstract: Argumentation is an important aspect in the field of education because of its impact on learning processes. At the same time, argumentation is a complex activity in terms of cognitive, relational, emotional and social dynamics. In this paper, I investigate and I describe possible difficulties encountered by children during the argumentative process. The study involves 25 preschool children at a kindergarten engaged in three building tasks. The tasks were video-recorded and the argumentative discussions transcribed. For the aim of this paper, I analyze how argumentation are distributed among participants. I select interactions in which participants apparently do not argue or there are differences in the degree of argumentative participation between participants of the same group. I analyze these interactions and moments of impasse in the argumentative steps. The findings show how the simplicity of solving the task (e.g., when children do not encounter any problem in completing the activity) and the children's self-perception of their competences in solving the task may have an impact on argumentation activities. Moreover, this perception is co-constructed by children within the interaction. The study contributes to the line of research on designing argumentation and highlights the role of the adult in managing children's interactions.

Keywords: argumentation; preschool children; competence; self-efficacy; design; problem-solving; socio-cultural psychology; collaboration

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1. Introduction

Argumentation is a process that is investigated since the preschool age (e.g., [1]). For example, some researchers have been interested in tracing its qualities in child development (e.g., [2,3]), while others have investigated argumentation as a key to accessing the child's cultural world (e.g., [4]) or to their ways of reasoning (e.g., [5,6]). Argumentation is widely explored in the field of education, especially in science education, as it is a process of critical reasoning that affects a child's learning [7] and pushes the students' knowledge further [8]. Argumentation it is also relevant for the development of young citizens [8]. For these reasons, the participation of young children in argumentative discussions is widely encouraged in the field of education. Although there is no doubt today that arguing in and out of the classroom is important, also recognized is how difficult it can be for a child to engage in such an activity. In this respect, a rich literature focuses on the observation of children's difficulties in arguing with peers and the adult (teacher). The aspects that have been investigated are mainly related to relational, affective, cognitive and social dimensions [9].

The present study is part of this line of research. Within a socio-cultural perspective, the aims are to investigate argumentative discussions among preschool children and to highlight the possible difficulties they encounter in the argumentative process. The education context of the study is STEM education at the kindergarten level in which children are asked to solve a technical problem together.

The understanding of barriers to children's active participation in argumentative discussion can offer to the teachers some useful tools to provide children with a positive experience within classroom debates.

The paper is organized as follows: first, I briefly review the existing research regarding children's difficulties during argumentative activities with peers and the adult. Second, I present the literature on designing activities planned to overcome some of the obstacles in argumentative tasks at school. Then, I introduce the methodological aspects of the present study on young children's argumentative interactions. Finally, I discuss the findings and address some final reflections in the conclusion of the paper.

2. Children's Difficulties in Argumentation Process

Argumentation is a "context-dependent activity" [10] (p. 7), and "argumentative analysis and evaluation cannot do without a proper consideration of context" [10] (p. 8). As the present study intends to investigate argumentative discussions among children in kindergarten, it is important to draw attention to the specific characteristics of argumentation in institutional contexts [7].

Arguing is a rather complex practice from a cognitive, relational, emotional and social point of view [11]. This complexity can be easily explained if we consider that argumentation, like other practices, is a form of interaction, an "argumentative interaction" [12]. However, when the context in which the actors are placed is the school, the required commitment increases and pupils' argumentation rarely occurs spontaneously [13,14]. In fact, while in family contexts children open up about different issues and discuss a large set of topics [15,16], in other, more institutionalized contexts, it is often the adult proposing the topic of the lesson and of discussion. In this regard, ref. [17] present ten rules of conduct for reasonable discussion. According to ref. [17] (p. 190), the "freedom rule" specifies that "discussants may not prevent each other from advancing standpoints or from calling standpoints into question".

Moreover, in educational institutional contexts, the teacher can be very demanding about student performance. The expectations that students have about the context can keep them from participating in a dialogue and, consequently, also in an argumentative discussion. Ref. [18] investigated some of the causes of students' low verbal participation in biology classrooms. Among the causes, some refer to causes of a personal nature (such as a deficit of attention or anxiety about being heard), others are related to the adult's intervention (such as the incentives he/she provides for participating), and others concern the proposed task (such as the lack of knowledge or understanding of the topic of discussion). Ref. [19] observed some preschool and school-aged children engaged in solving building tasks. The authors recognized the children's need to find an interactional space, including a physical one, as a prerequisite for participating in argumentative discussions.

In adult-child or child-to-child argumentative activities in the classroom, the mutual commitment is not only to produce arguments, but also to use the dialogue as a mean to maintain a constant propensity to understand the other's argument [20]. The dialogical process can be hindered when children and adults do not share the same implicit cultural premises [4,21]. Power relations between the adult and the child, as well as the institutional expectations that children have about how to answer and how to interact with the adult [22,23], can have a negative effect on the interaction by reducing learning opportunities. In the case of these dynamics with the adult, it is very important to maintain a collaborative relationship with the peer group.

The variety of studies briefly reported here indicates how argumentation is as important as it is complex for pupils in institutional context. For this reason, the next section of the paper focuses on the design of argumentative tasks intended to overcome some of these obstacles.

3. Argumentative Design in Activities with Children

Some research focusing on argumentation in pedagogy paid attention to the design of school tasks. The term "design" refers to the construction of situations that support participants to engage in argumentative tasks.

The line of research called *arguing to learn* [24] has extensively examined the design features that best promote the development of argumentative activities in school tasks. Indeed, this line of research considers argumentation as a tool for promoting knowledge and a mean through which it becomes possible to foster learning. In this sense, designing within the arguing to learn line aims to accompany students in expanding and pushing forward their knowledge within argumentative discussions. Thus, the role of the design is important because of its effects on knowledge acquisition through argumentative practices.

This view implies the need to think about the context and the conceptual framework in which an argumentative activity is constructed and promoted for various purposes.

Concerning the argumentative activity in school, designing is not an easy task because the activity itself is a complex practice [24,25]. The designing choices are linked to the researcher's goals. Within the arguing to learn approach, Ref. [8] (p. 183) indicate that a good argumentative discussion must meet two criteria: the engagement and the productivity. The authors refer to the engagement as the high participation of people involved in an interaction. The term also indicates a high responsiveness to others' interventions, to the coordination of all interventions rather than the presentation of parallel ideas (As it is the case in the cumulative talk [26], described as repetitions and accumulation of different ideas.), and to the discussion and the difference of opinions centered on an epistemic level, rather than personal [27]. Another element is the interlocutors' willingness to question and challenge the standpoints advanced by others. Ref. [8] refer to the productivity to indicate how, in a process in which different points of view are discussed, the interlocutors are willing to collaborate and bring mutual respect to each other, when learning is extended to other activities than the one in which the project is carried out.

Starting from these elements, it is possible to identify some principles that are likely to foster a discussion with the above-mentioned approach. One principle concerns the problematization that occurs when a question raised by the teacher is identified as interesting and problematic by the students [8]. For this purpose, the adult can propose semi-structured and unstructured problems for which everyone can contribute with his/her own knowledge because there is not a single possible solution. In this case, it is relevant to emphasize the active role of the adult in encouraging, through questions, critical student attitudes [8].

Another principle concerns the role of the adult during the activity, based on the idea that the task is not only designed before the interaction, but also during it (through the adult's interventions) [8]. This can have long-term effects on the students' interactional attitudes, even when the teacher is not present [20]. The interventions having positive effects are those related to a request for clarification and explication of a reasoning, or to check the soundness of the advanced arguments. In the context of this line of research, the impacts of technological devices on the development of arguments have been investigated in terms of digitized maps, in which the standpoint and the arguments expressed by participants can be presented to the entire group (e.g., [28]).

A further line of investigation refers to the use of texts and hypothesis testing devices. These are intended as supports offering alternative standpoints that, presumably, can produce cognitive (or socio-cognitive) conflicts and can be implemented by students through argumentation. In the context of the hypothesis testing devices, the introduction of a tool that possibly contradicts the knowledge of the user is not sufficient, as the result of the tool may be ignored; on the contrary, the use of the tool with a request to reach the consensus among participants seems to have better effects [29,30].

Based on these elements, in the next section of the paper, I present a study in which three tasks of technical problem solving have been designed by the adult to support preschool children's argumentative activities.

4. Goal

The study's aim is twofold: to investigate argumentative discussions among preschool children involved in problem solving tasks, and to highlight possible difficulties encountered by children in the argumentative process.

I adopted a socio-cultural psychology perspective to look at how argumentation is dynamically co-constructed during the interactions in the context of production [31–34].

5. Method

5.1. Participants and Data Collection

A group of 25 children (male = 13; female = 12) aged 3 to 5 years (mean age = 4 years 8 months) was involved in the study. The data were collected by the author within a project on children's implicit argumentation (Research project "Analyzing young children's implicit argumentation", funded by the Swiss National Science Foundation, grant n. 100019_156690, applicants: A.-N. Perret-Clermont, S. Greco, A. Iannaccone and A. Rocci). After having obtained all the necessary permissions, the procedures to ensure anonymity and to guarantee the ethic management of the data were established for the entire research process.

Data were collected in the autumn 2016 in a kindergarten in Italy. Previously, I spent one week in the kindergarten to participate with teachers and children in their everyday activities (e.g., welcoming children in the kindergarten, having free play time, attending lessons). This period allowed the researcher to become familiar with children and the environment, and vice versa. Data collection was carried out in the toy library of the kindergarten. This room had two glass walls overlooking the kindergarten's backyard and another indoor classroom.

The activities were recorded: an audio recorder was placed on the worktable of the toy library and a camera in front of the worktable. Children were asked to engage in three different activities: building a tunnel with Legos® in such a way that a car could pass through it; building a bridge with Legos® to connect two opposite points of a river; and building an hourglass with recycled materials. Children were divided in 7 triads and 2 couples. Each group participated to the three activities. A total of 27 recordings, lasting about 16 h, were collected.

5.2. Presentation of the Activities

The three activities proposed to the children have been designed according to previous studies on argumentative designs.

5.2.1. Building a Bridge

The activity is inspired by [35] and consists of building a bridge with Lego® bricks. The materials include a box of Legos® of small size, a box of Legos® of big size, a blue paper, two toy cars, and two mannequins. The blue paper is taped to the worktable. The toy cars and the two mannequins are placed at opposite sides of the paper. The adult asks children to build a bridge with Lego® bricks in such a manner that the mannequin (representing two friends) could pass over the lake (the blue paper) by car (the toy cars).

This task intends to promote the participation of all children in the activity by using the Legos® of the size and shape they prefer. The adult does not give any specific instructions on how the bridge should be. The request of building a bridge per group intends to put children in the situation of being obliged to face potential individual differences during the work.

5.2.2. Building a Tunnel

The activity is inspired by [36] and consists of building a tunnel with Lego® bricks. The material adopted for the activity includes four images of different kinds of tunnels, a box of Legos® of small size, a box of Legos® of big size, and a toy car. The adult invites children to build a tunnel in such a manner that the toy car could pass through it.

The task is designed by considering studies about the effects of texts proposing different points of view and the hypothesis testing devices on the argumentative activity (cf. Section 3). Both have the potential to provoke a socio-cognitive conflict that can be solved (under certain conditions) by means of argumentation. In order to implement in the activities "texts proposing different points of view" to preschool children, four images are adopted. Moreover, the task is designed in such a way that the "hypothesis testing device" is somehow included in the researcher's instructions. The adult's request is to build a tunnel to allow a toy car to pass through it. Whether the car fails to pass through it, the idea that the tunnel is adequate for the aim of the activity is contradicted. This event could ideally stimulate children's argumentative debates.

5.2.3. Building an Hourglass

The activity is inspired by the foundation *La main à la pâte* (See http://www.fondation-lamap.org/en/international (accessed on 7 March 2021)). and consists of building an hourglass with recycled materials including a small-scale model of the object, two little plastic bottles, a plastic box containing sand, three small spoons, a tape, a pair of scissors, and three funnels.

As cooperation is an important aspect of designing an argumentative task (e.g., [30]), the construction of an hourglass ideally encourages the joint participation of all children, because the available material is sufficient to build only one hourglass. Accordingly, the product can be realized through the joint children's contributions. To achieve the goal, one of the two bottles must be filled with sand, while the second one must be turned upside down on the first bottle. Then, the two bottles must be sealed together with the tape. If (at least) one child is committed to holding the bottles, the presence of someone else committed to apply the tape is necessary.

5.3. Data Analysis

The software Transana Basic 3.10b was used to select the episodes of argumentative discussion within the recorded data. These episodes (N = 65) were transcribed by using a simplified version of the system elaborated by [37]. The symbols of transcription are indicated in Appendix A. Based on the transcripts, the following elements were identified: the issues occurring in each argumentative episode; the standpoints and the arguments; and the argumentative structures (according to the pragma-dialectical approach, see [17,38]). For the detection of the implicit premises connecting each argument to its standpoint, the Argumentum Model of Topics [39] was applied.

As a second step, by going back and forth between video recordings and transcriptions, an analysis of how argumentation is distributed among the participants was performed. Firstly, I selected the cases in which argumentation is less frequent. Then, I turned back to the videos to observe the activity and to describe the interaction. In order to classify an argumentation, the following criteria must be present: a problem to be solved (the "issue", e.g., [40–42]); a difference of opinion regarding the problem; and the presentation of one or more arguments.

Instead of focusing on single pieces of conversation, I analyzed how the interaction changes over time with the idea of highlighting the argumentative passages in which an impasse may eventually occur. Ref. [12] describes two different modalities in contrast with argumentation of "solving" a problem: "Firstly, people could try to ignore the problem: perhaps one person does not want to offend the other by appearing "difficult;" perhaps there is a general feeling that the question is not sufficiently important to merit deeper discussion; perhaps they are short of time and want to move on, and so on. Secondly, people could restrict themselves to a simple exchange of divergent opinions: "yes that's right/no it isn't/yes it is...." But such an approach does not generally produce the required result" (p. 128).

6. Results

A total of 89 children's argumentations were identified in the corpus and classified in 6 cases of multiple argumentative structures, 12 cases of subordinative argumentative structures, 3 cases of coordinative argumentative structures, and 68 cases of simple argumentative structures. A total of 110 arguments were identified. The analysis of the implicit premises shows a variety of implicit premises of inferential and contextual nature. For example, children reason regarding complex aspects of an action, such as the relation between tools and goals, the relation between an action and its consequences, the relation between the final result and its intermediate steps or the legitimacy of an action [6,43].

Despite the high number of children's arguments, results revealed cases in which no argumentation was performed or there was a discrepancy between the children's participation and the lack of argumentative production.

To better investigate this specific result, I selected three illustrative cases in which the argumentative activity performed by the children is not the one expected by the adult.

6.1. Illustrative Cases

6.1.1. Case 1: "I don't Know How to Make a Bridge"

Case 1 concerns a sequence involving three children, Mia (4 years 7 months), Giacomo (5 years 2 months) and Fulvio (4 years 6 months), who are building a bridge with Lego® blocks.

Firstly, I describe the activity performed by participants for 16 min (since the beginning of the task). After the adult's presentation of the task, children begin to build the bridge. Mia and Giacomo work separately. Fulvio checks pieces in the box. The researcher reminds children that they have to work together to build only one bridge. However, Mia and Giacomo continue to work separately. Fulvio is engaged in the exploration of the material. He raises one of the mannequins, attaches it to a piece of Lego® shaped like a wheel and makes it from one side of the paper to the center. Again, the adult invites children to work together, so the work would get done faster.

After 10 min, Mia looks at Fulvio and asks: "Fulvio, can you help us instead of playing?" She identifies his activity as "playing" and she takes the objects out of his hand, placing them into the box. Fulvio raises the wheel and says: "I want to have a swim." Thinking that children are struggling with the activity, the adult decides to give them the Legos® of big size. Fulvio raises the wheel again and adds: "I want to have a swim." Mia answers: "You can't go there anymore", taking the wheel out of his hand and placing it into the box. Then, Mia starts working with Legos® of big size and Giacomo continues to work with Legos® of small size. Fulvio picks up a piece of Lego® and tries to attach it to Giacomo's construction. He does not succeed. Giacomo says: "Look, how to do it", attaching the two pieces. Fulvio tries to add a piece to Giacomo's construction, but he fails. Giacomo says: "No, don't destroy it." The construction breaks into two. After a few seconds, Fulvio raises again the wheel and says: "I go to the lake." Mia says: "Fulvio, can you stop playing?" Then, Fulvio takes a piece of Lego® and asks Mia: "Can I put this?" (on Mia's construction). Mia answers: "No, can you go to build your bridge?" Then, she raises her construction and looks at the researcher.

After about 16 min since the beginning of the task, the adult, trying to convince the participants to work together, suggests they put together their constructions. In this moment, Fulvio makes explicit that he does not know how to make a bridge:

((Hour: Minute: Second): 0:16:12.5)

Adult: = maybe you can put together the pieces you have made

Fulvio: [I don't know how to make a bridge]

Mia: [Giacomo uses the small ones] Giacomo uses the small ones ((she points with her finger at the Giacomo's construction. She is referring to the size of the Lego®))

((Hour: Minute: Second): 0:16:27.6)

In the excerpt, when the adult invites children to put together their constructions, Fulvio answers: "I don't know how to make a bridge." In Fulvio's eyes, his difficulty in participating in the activity (as the adult is expecting) is related to a lack of competence in the building work. However, these children are used to playing with Legos® at the kindergarten, almost every day. The present activity was designed in such a way in agreement with the teacher and according to previous similar pedagogical activities. Following a socio-cultural perspective [44], Fulvio's self-perception of his competence (The definition of self-perception of competence adopted here follows [45]): "The self-perception of competence is a psychological variable that reflects the judgment of people about their own abilities to mobilize resources in order to achieve a particular goal.") has potentially been co-constructed and consolidated within the interaction. The problem in the interaction between Fulvio, Mia and Giacomo (and the adult) is that Fulvio is unable to build a bridge autonomously during the first phase of the activity. At the same time, the adult and the other children are not recognizing Fulvio's request of help. In this way, Fulvio never got a chance to fully experience and show his building competences. He tried channeling his participation into other activities (for example, choosing pieces of Lego® in the box or playing with the wheel).

Although the adult was soliciting children several time during the activity (as the role of the adult is continuously developed during the activity, based on the idea that the task is not only designed before the interaction, but also during it, through the adult's interventions [20]), her interventions had no positive effects on supporting the children's argumentative interaction.

The entire activity lasted about 30 min. At the end, Fulvio was not able to manage the construction of the bridge: he was just following the classmate's actions, although Giacomo never shared in an explicit way his plan and project with Fulvio. Since argumentation requires a problem to be solved [12], argumentation fails at a basic level.

6.1.2. Case 2: "The Work Is Too Easy"

Case 2 involves other three children (Elsa, 4:4 years, Sally, 5:3 years, and Camille, 4:6 years) who are building the bridge. At the beginning of the activity, the researcher introduces the "phase of exploration" and invites children to look at what they have around (she runs her hands over the table). She tells them that she will be back soon to present the activity. Elsa says: "I have a red chair", Camille says: "Me too", and Sally adds: "And I have the yellow one." They remain silent for some seconds and start looking at the researcher. Then, the adult asks: "Do you want I come explaining the activity?" The children agree and the researcher introduces the "phase of presentation of the task". She presents only a part of the instructions for the activity because the children want to describe how they spend time with friends. This phase lasts about 3 min. After, the researcher summarizes the instructions:

((Hour: Minute: Second): 0:03:34.5)

Adult: these two people are two friends, they want to be together, but here there is a river that divides them and they cannot meet, but they want to be together. So, I have found a solution, if you like. You can build a bridge with Lego®, to bring them together, would you like that? you have to make one bridge all together and when you're done, you call me, okay?

Camille: yes

Sally: yes

Elsa: ↑ I don't know how to make it ::

Adult: help you each other (.) try it

((Hour: Minute: Second): 0:03:53.2)

As in Case 1, a child makes explicit the fact that she does not know how to realize the work (Elsa: "↑ I don't know how to make it ::"). The adult invites the children to collaborate.

Contrary to the group of the first example, here Camille and Sally complete the activity in one minute and this prevents any changes in the interaction (in Elsa's possibility to exercise her skill and to change her self-perception on her competence). In fact, for the next 4 min, Elsa and Sally explore the content of the box (Elsa finds another mannequin and plays with it), while Camille tries to start building the bridge, although not all the pieces of Lego® she is using fit with the others (she asks for the adult's help). After exploring the box, Sally starts the building activity but, after few seconds, she leaves the construction and plays with a mannequin. Then, Camille says: "Let's make a bridge" and "The bridge is here" while putting the first piece of Lego® on one side of the paper. The bridge she is making is very simple, like a line of pieces of big size. Sally sees it and puts some additional Legos® on it. After one minute, Camille says: "We have already finished the bridge." All the children move the mannequins over the bridge and let them meet each other. The adult observes it and congratulates the group.

In Case 2, neither Elsa nor Camille and Sally worked in the appropriate context to develop an argumentative discussion. Elsa does not have space and time to prove her competence (and then to access the problem). Camille and Sally did not meet any real "problem": on one hand, Camille and Sally did not perceive the question raised by the adult as problematic; on the other hand, they decided to engage in a simple task (For the investigation of the reasons behind the choice of tasks with different degrees of difficulties by preschool children, see ref. [46]). Accordingly, there was no process of problematization [8].

6.1.3. Case 3: I Know How to Make Bridges

Case 3 concerns a group of three children who are building a bridge: Giacomo (4:8 years), Carlo (5:3 years) and Maria (4:9 years).

At the beginning of the sequence, the adult gives the children some time to assess the available material placed on the table. Then, she presents the activity by inviting the children to build a bridge in such a way so that two friends who live on the opposite sides of a lake can meet. She specifies that the children have to work together to build one bridge. Each child grabs two pieces of Lego®. Maria says: "I know how to make bridges" and starts building a bridge shaped like an arc. Carlo tries to take a piece of Lego® from the hands of Maria, but he fails. Maria continues to attach pieces of Lego®. The children are making three different bridges but, at some point they compare their works:

((Hour: Minute: Second): 0:07:11.0)

Maria: in the bridge I will put these ((she finds two Lego® shaped as rectangular central opening))

Carlo: xxx are like this

Giacomo: no (.) the bridges are like this look Carlo

Carlo: no (.) the bridges are like this

Maria: the bridges are also like this look (.) as I do ((she attaches the Lego® to her construction)) teacher :: teacher :: the bridges are like this look (.) I'll show you children

Carlo: it doesn't look like a bridge to me ((he looks at Maria's work and he shakes his head))

Maria: bridges are like this

Carlo: no ((he shakes his head))

Maria: looks like a bridge to me

Carlo: not to me

Giacomo: no (.) bridges are like that too

Carlo: no (.) maybe some (.) xxx

Maria: here (.) I made the bridge ((she built a part of the bridge)) give it to me and attach it ((try to grab the piece built by Carlo))

Carlo: no (.) that is not a bridge

Maria: come on :: ((Maria tries to attach the Giacomo's construction to her work, but Giacomo takes the pieces)) Come on :: I don't know how to build bridges

((Hour: Minute: Second): 0:08:16.0)

In Case 3, Maria's participation in the activities changes over time and in the degree through which she perceives herself as competent in the building task. Differently from Cases 1 and 2, at the very beginning of the activity the child immediately engages herself in the work. Moreover, she makes a positive comment on her competence: "I know how to make bridges." Her construction shaped like an arc is very similar to bridges built by other children in different recordings. Here we found a first moment of impasse in the collaboration when Carlo tries to take a piece of Lego® from the hands of Maria. A second moment of impasse is when Maria decides to add to the construction two Legos® of rectangular shape with a central opening. Carlo and Giacomo look at her work and the three children start making comments on the others' realizations. Carlo makes explicit that Maria's construction is not a bridge ("it doesn't look like a bridge to me"), but Maria disagrees ("bridges are like this"). For several moments, they present opposite standpoints about Maria's work, although without supportive arguments. The self-perception of Maria about her competence in solving the task changes. She says: "I do not know how to build bridges" and stops working. The adult reminds children to work together and the group start again to build the bridge (Giacomo on one side of the table and Carlo and Maria on the opposite side). As in Case 2, the children's work is very basic and they complete it in a short time. In this phase, Maria manages to add only one piece to the construction that Carlo relocates. After few seconds, Giacomo says: "Here is the bridge", announcing that they managed to complete the work and to connect the opposite sides of the lake.

In Cases 1 and 2, the moment of impasse in the argumentative interaction was due to the fact that the participants were not dealing with the problem. In Case 3, the situation is different. The issue is to qualify (as a bridge or not) the construction made by Maria. Despite the problem to solve, in Case 3, the children limit themselves to exchanging divergent opinions [12]. Their conflict seems to be more based on the affective level, rather than the epistemic one [47]. In fact, the children's interventions end with the following statement of Maria: "I don't know how to build bridges". This position related to Maria was co-constructed within the interaction with a negative effect on the argumentation process.

7. Discussion and Conclusions

Although there is no doubt that arguing in and out of the classroom is important because of its impact on learning processes [8,48], it is also recognized how difficult it could be for a child to engage in such an activity. A variety of studies investigated difficulties pupils encounter during argumentation in institutional contexts. As a result of these researches, arguing and learning are described as processes involving complex cognitive, relational, emotional and social dynamics [11,49,50].

In this paper, I investigated argumentative discussions among preschool children by taking a socio-cultural perspective, and I described possible obstacles children encounter during the argumentative process.

To move a step forward within this frame, in this paper I carefully designed three tasks of technical problem solving before proposing them to children. I adopted the frame of studies dealing with the "design" of tasks intended to support participants in engaging in argumentative discussions (e.g., [25]). These studies, as the one included in the line of research called *arguing to learn* [24], have extensively examined the design features that best promote the development of argumentative activities in children at school age. For the sake of the present paper, I adapted the *arguing to learn* line of research to situations involving preschool children (at a kindergarten) engaged in building tasks related to technical problem solving. In order to do so, the first activity concerned the task of building a tunnel, the second was related to build a bridge—both with the use of Legos®—and the third asked participants to build an hourglass with recycled materials.

The multi-step analysis focused on the following aspects: (1) the identification of the children's argumentation, (2) the reconstruction of the structure of each argumentation, and (3) the identification of their implicit premises. The findings show that children construct complex argumentative structures, and their arguments are based on a variety of implicit premises of inferential and contextual nature, advancing reasoning regarding complex aspects of an action [6,43].

As second step, I examined how argumentations are distributed among participants and I selected cases in which argumentation appears less frequently. By turning back to the videos, I identified the moments in which an argumentative impasse occurs [12]. Instead of focusing on single pieces of conversation, I analyzed how the interaction changes over time with the idea of highlighting the argumentative passages in which an impasse may eventually occur.

The present study highlights two phenomena that can potentially have an impact on the investigation of argumentative interactions.

The first one refers to the case in which the activity appears to be too easy for the children: in this case, they do not perceive the "problem" to be solved. This occurs when the children easily find a way to solve the task. For example, while building the bridge, some children decided to use Legos® of small size and built very complex structures (e.g., a concave structure), while other groups (see Cases 2 and 3) built very basic bridges and completed the activity in a short time. In these situations, the process of problematization [8] that is necessary to introduce an issue did not occur. This was the effect of a co-construct between participants: on one hand, the question raised by the adult was not problematic for the children; on the other hand, children engaged in a simple and quick task.

Secondly, I refer to the cases in which the children's negative/limited self-perception of competence [45] in solving a task potentially contributes to elicit the "exit" of the children from the activity. Since argumentation requires a problem to be solved [12], when the children did not deal with the problem, argumentative interaction fails. The concept of self-efficacy and how it is influenced by the context (peer interactions, family and school settings) is largely present in the theory of Bandura. However, as the present paper aims to rely on argumentation, a specific focus on the concept of self-efficacy is not offered. For further details, cf. [51], 1994.

Moreover, children's negative/limited self-perception of their competence is co-constructed within the interaction. Not surprisingly, adults (teachers, parents) can have diverse perceptions of the same child referring to his/her competence and this can impact the child's future performance (e.g., [52]).

The findings of the present study suggest useful insights for teachers of early childhood science education. In school interactions, a child "brings with them a history of positive and negative social encounters, a preferred pattern for interactions, and temperament characteristics" [53] (p. 102). However, adults also enter into these interactions and can have an impact on encouraging children in managing the activity. For example, the adult has the role to select the appropriate degree of difficulty of a task according to the children's ability and familiarity with the task (e.g., [54]), within their zone of proximal development [55]. However, the adult also needs to adapt the difficulty of a task after the beginning of the activity, according to a context's change. The adult also has the role of promoting the children's positive exploration experiences of their competences [45,56].

Despite the adult's efforts in designing the tasks, the argumentative process has not always been successful, as expected. Nevertheless, the careful attention needed to design tasks highlights some preschool children's difficulties in the argumentation process that are different from those already described by the literature in the field of children's argumentation at school age (cf. Section 2). For this reason, the present study contributes to the line of research of design in argumentation, by exploring more in detail children's difficulties and by presenting adult's responsibilities during activities at preschool age.

I intend to conclude this work with some methodological remarks. I am conscious that some challenges stem from the research design adopted for the present study. I recognize that the limited number of recordings favored a careful analysis of how the building activity was interpreted and realized by participants, but did not allow elements for quantification and generalization. A larger database would probably expand the possibilities to identify relationships with different factors, such as gender, group composition, etc. Further studies and more in-depth analyses will contribute to address these concerns.

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Appendix A Transcription Symbols

Sign	Description
(( ))	nonverbal information
=	latching
[	overlapping
::	extensions of sound
(.)	short pause
↑↓	increasing or decreasing intonation
Xxx	non-understandable utterance

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education sciences

Article

How Do Five- to Six-Year-Old Children Interpret a Burning Candle?

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Abstract: Many studies have been conducted in recent years on the explanations given by preschool-age children about different natural phenomena. Nonetheless, very few studies have actually focused on the important domain of matter and its transformations. Specifically, the field of chemical reactions remains unexplored. This qualitative study aims to investigate the explanations of twenty-two 5- to 6-year-old children about combustion, while at the same time evaluating the effect of prior experience with science activities on their interpretations. For this study, the following experiment was proposed: burning a candle inside an inverted vessel. The following data collection tools were used: a Predict-Observe-Explain (POE) strategy and audio and video recordings. The children's explanations were analysed using classification frameworks, which had been developed in previous studies. The results of this study suggest that young children tend to provide naturalistic explanations about combustion. This finding is an indicator that young children are able to construct mental representations within this conceptual domain. Likewise, the results indicate that children who are used to engaging in inquiry-based activities may be more likely to establish a relationship with previous learning experiences to interpret other natural phenomena.

Keywords: preschool children; explanations; precursor models; natural phenomena; combustion

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1. Introduction

Young children have a natural curiosity and an innate desire to explore the world around them [1]. It is important that we use this enthusiasm and desire to learn to engage young children in science, taking into account the well-documented benefits, which include improved intellectual and linguistic development [2]. Moreover, exposing children to scientific phenomena at an early age provides them with a solid foundation, which will enable them to further develop scientific concepts and attitudes that will be presented to them at higher educational levels [3].

The current consensus suggests the need for preschool-age children to be engaged in the scientific practice of developing and using models, given their ability to construct their own theories and models about the world through an induction process [4]. These internal representations are formed through their interaction with the natural, social, and cultural environment in which young children develop [5]. As a result, the main aim of including science in early childhood education is not for young children to acquire scientific concepts, but to encourage them to question their own models and construct new ones that are increasingly closer to the models of school science [6]. Therefore, it is important to note that young children's models or explanations should not be evaluated as 'right' or 'wrong' [7].

There is an extensive body of literature in the field of science education which deals with students' views on matter and its transformations. Nonetheless, the majority of these studies have focused on primary and secondary school students (see, e.g., [8]) and, as a result, the information regarding the kind of explanations or representations that very young children construct about phenomena in which transformations of matter occur is very minimal. Specifically, the introduction of the chemical reaction concept in early childhood education is a field that is yet to be researched.

This paper aims to investigate young children's representations and explanations of the everyday phenomenon of burning a candle, which is intimately related to the transformation of matter. This study was guided by the following research question:

What types of explanations do young children use when reasoning about combustion? To what extent can these explanations be considered as indicators of the existence of a precursor model, and to what extent may children's familiarity with science activities influence the interpretations they construct?

1.1. Precursor Models and Explanations in Young Children

Within the field of cognitive science, it is widely accepted that individuals develop and use internal representations that allow them to explain facts and phenomena of the world around them [9,10]. The mental model construct was originally described by psychologist Craik [11], who suggested that people have a small-scale model of how the world functions engrained in their minds. A few decades later, psychologist Johnson-Laird [12] built on Craik's idea, defining a mental model as a reasoning mechanism, which enables people to understand phenomena and make inferences.

Within the field of science education, Gilbert [13] understands a mental model to be a private and personal representation that is developed for a specific purpose by an individual, either alone or as a part of a group. Since mental models are conceived as generative tools, these allow people to explain, predict and describe multiple phenomena [14]. Mental models may involve distortions or alternative ideas, which can lead to inaccurate explanations [15]. However, these internal representations are dynamic in nature, and, as such, they are constantly subjected to a review process with the goal of removing internal contradictions [16]. In this way, models that differ from school science models in terms of content can reach a higher level of sophistication if adequate teaching strategies are implemented.

From an early age, children feel an innate need to develop models that enable them to interpret the world around them, and in order to do so they use the resources that are at their disposal [17]. These initial models, which are known as precursor models, are cognitive structures that are built on certain core elements, which are included in the scientific models [17,18]. Although the range of application of precursor models is limited, only allowing simple causative correlations, they constitute the bases on which the school science model is built [17,19]. If these bases did not exist, the school science model would be very difficult or impossible to construct [20].

Based on the precursor model approach, some studies have investigated how these representations are formed in young children's thoughts. Ravanis et al. [18] found that 5- to 6-year-old children were able to construct a precursor model of thermal expansion and contraction of metals that allowed them to predict and explain phenomena within this conceptual domain. This precursor model was established and expanded through experimental activities, based on a Predict-Observe-Explain (POE) teaching strategy. Koliopoulos, Tantaros, Papandreou and Ravanis [19] also concluded that 5- to 6- year-old children were able to construct a precursor model of flotation that is based on an intuitive concept of density.

As mentioned above, mental models enable people to construct explanations. The construction of explanations is considered one of the most important discursive practices in science teaching [21]. However, there is still no consensus definition of the term "explanation" in the literature [22]. Gilbert, Boulter and Rutherford [23] stated that a simple definition would consider the meaning of "explanation" as the response given to a specific question. Other authors such as Braaten and Windschitl [24] have pointed out that students are able to generate explanations to clarify meanings or describe the reasoning used when answering a given problem (explanation as explication), define the causal mechanism of a phenomenon by establishing cause-effect relationships (explanation as causation, or justify an idea (explanation as justification).

Legare [25] pointed out that characterising children's explanations about the physical world provides crucial information about the mechanisms that this collective activate in order to understand the environment, acquire new knowledge, and develop causal learning. Based on Piaget's theory of cognitive development, young children resort to non-naturalistic explanations in their accounts of natural phenomena, since the boundaries between the real and the mental world are diffused at an early age [26]. As a result, young children tend to construct explanations in which life and intentions are attributed to inanimate entities (animism), in which certain psychological processes such as dreams or thoughts really exist (realism), or in which it is assumed that everything that exists around us has been created by the human being with a specific purpose (artificialism).

However, recent research studies have suggested that preschool-age children are able to give spontaneous explanations of different natural phenomena, in which an incipient understanding of the physical causality is appreciated [27,28]. Hickling and Wellman [29] found that even at 2–3 years of age, children were able to construct causal explanations, with the occurrence of this type of explanations increasing with age. A study conducted by Christidou [30] found that most 5- to 6- year-old children attributed the occurrence of phenomena such as flotation, magnetic properties, and dissolution to certain intrinsic properties of the substances or objects that were involved in the process. For instance, young children mentioned that the object sunk due to its weight or due to the material that it was made of. In a subsequent investigation, Christidou and Hatzinikita [27] concluded that 5- to 6- year-old children give naturalistic explanations about plant nutrition, assuming the intervention of an external agent. For instance, the participants mentioned that plants are able to grow thanks to human beings watering them. A naturalistic explanation is rational and this is considered as the beginning of physical causality [5,27,30,31]. Other authors such as Saçkes, Flevares, and Trundle [32] characterised the understandings of twenty-two preschool-age children (aged 4 to 6) regarding the rainfall mechanism. These authors observed that the older children were able to construct plausible explanations about this phenomenon, referring to the idea that the water is stored in different locations, such as the clouds or the sea, and that rainfall simply involves the water changing location.

On the other hand, they found that young children used different modes of explanations depending on the entities that were being considered. For instance, preschool-age children often used psychological reasoning for human beings, biological reasoning for living things, and physical reasoning for inert entities [29]. Christidou and Hatzinikita [27] also found that the young children's familiarity with the phenomenon had an impact on the explanatory mode that they selected.

1.2. Previous Research on the Concept of Matter and Its Transformations

In recent years, many studies have been conducted on the conceptions of preschool-age children on natural phenomena. Nonetheless, only a small number have investigated the topic of matter. Most of them have referred to other conceptual domains such as rain formation, flotation, plant growth or magnetic properties (see, e.g., [27,30,32]. Therefore, in an effort to summarise the students' conceptions of the concept of matter and its changes, we have presented descriptions by children of a range of ages, beginning with those in early childhood education before ending with a brief reference to primary and secondary school students.

In early childhood education, Cruz-Guzmán, García-Carmona, and Criado [33] investigated how young children (aged 2 to 4) learned about changes of states through an inquiry-based approach. These authors found that many children were able to understand that when ice is heated it turns into liquid water. However, none of the participants were able to understand the reverse process. Bar and Galili [34] compared the responses of children of different ages to questions about drying laundry and water evaporating from a container. The authors concluded that the younger children (aged 5 to 7) were able to describe evaporation as the disappearance of water, but that the concept of water being absorbed into the surfaces only emerged among children from the age of seven. Tytler and Peterson [35] also explored the ideas of five-year-old children regarding the evaporation phenomena. Unlike Bar and Galili [34], these authors found that young children were able to grasp the idea that liquid changes position, for example, by absorbing into surfaces or by going to the clouds, therefore suggesting that their thinking is more complex than expected. Moreover, Tytler and Peterson [35] concluded that young children do not have a mental model that enables them to explain how the water might exist in a non-perceptible form in the air.

On the other hand, Kambouri and Michaelides [36] investigated the effect of an intervention in which drama techniques were used on the young children's understanding of the water cycle. The results indicated that prior to the intervention, the participants (aged 4 to 5) found it difficult to define how clouds are formed, referring to the intervention of divine entities. After the intervention, many young children managed to acquire vocabulary relevant to the water cycle (e.g., vapour), and they were able to provide much improved explanations of what the rain is or what the clouds are made of. A recent study by Malleus, Kikas and Marken [37] also examined kindergarten and primary school children's understanding of cloud formation and rain. These authors concluded that, although some of the younger children (aged 5 to 7) mentioned that the clouds are made of water vapour, most of them relied on the observable aspects of the phenomena (e.g., the idea that clouds are made of cotton or smoke).

The ideas of primary and secondary school students concerning the concept of matter have been well documented in science education literature. With regard to the particle nature of matter, Özmen [38] concluded that children (aged 12 to 13) considered the existence of other material such as air between the particles. In terms of the conservation of matter, Hesse and Anderson [39] found that 11-year-old children considered that matter is not conserved in the reactions in which gases are released. Regarding physical changes, Ahtee and Varjola [40] found that a widespread alternative conception among students (aged 12 to 14) was the idea of considering dissolution and changes of state as a chemical reaction. It must be clear that the substances remain the same during a physical change, whereas during a chemical change a break and formation of new bonds between atoms occurs, which enables the initial substances to be transformed into other different substances. Prain, Tytler and Peterson [41] found that 11-year-old children describe the condensation of water vapour as a transmutation of cold into liquid water, or as the leakage of water. With regard to chemical reactions, Eilks and Moellering [42] concluded that children (aged 12 to 13) did not conceive the existence of chemical reactions in the case in which one initial substance formed other substances. In the case of combustion, it was observed that the students' explanations about this phenomenon depended on the combustible material. Meheut, Saltiel, and Tiberghien [43] concluded that children (aged 11 to 12) described the combustion of wax or metal as melting or evaporation. BouJaoude [44] found that students (aged 13 to 14) explained the combustion of alcohol as evaporation, and the combustion of wood as the change to ashes. Prieto, Watson and Dillon [45] argued that the inconsistency in the student's interpretations is due to the fact that they are beginning to reconstruct their mental models in the search for great explanatory power.

According to Kypraios, Papageorgiou and Stamovlasis [46], many of the difficulties that children experienced when dealing with the concept of matter were derived from their limited understanding of the particulate nature of matter. Developing a deep understanding of the particulate nature of matter is essential in order for students to be able to explain the changes that occur at macroscopic level [47].

2. Materials and Methods

This study involved a qualitative methodological approach, since it sought to describe, become aware of, and gain an in-depth understanding of a phenomenon of interest in context-specific settings [48]. It is important to consider that due to the qualitative nature of the research, which involved a small sample group, the generalisation of the results is limited. However, this paper includes comparisons with other studies of a similar nature, therefore contributing to the knowledge of young children's explanations about phenomena in which transformation of matter occurs.

2.1. Participants

A total of 22 preschool-age children, ten girls and twelve boys, participated in this study. The participants' ages ranged between five- and six-years old. The research was conducted in two public schools in north-west Spain. Eight children, three boys and five girls, attended a school located in a mid-sized city, and these children were accustomed to more traditional teaching methodology, with little room for the inclusion of science activities. From this point on, we will refer to this group of children as group A. Fourteen children, five girls and nine boys, attended a school located in a rural area, and these children were used to doing different science projects in the classroom. From this point on, we will refer to this group of children as group B. The difference in the instruction received by the two groups of participants will allow us to determine to what extent the young children's familiarity with science activities influences the way in which they construct their explanations.

Some weeks before the intervention, group B had engaged in several guided-inquiry activities related to changes of states, as part of a science project about the water cycle. Inquiry-based learning is an approach that is frequently used in science education, and the main goal is for students to infer meaning, with learning focused on questioning, critical thinking and problem solving, in which the teacher acts as a learning facilitator [49]. One of the learning activities consisted of filling a container with water so that the students could measure how the water level decreased over the course of several days. This allowed the teacher to introduce the idea of evaporation. Another activity consisted of placing a mirror over the water vapour that was being released from a kettle, so that the children were able to see how the vapour changed into liquid water again. This allowed the teacher to introduce the idea of condensation. None of the children had previously engaged in any activities concerning combustion.

In terms of the ethical considerations, it is important to mention that we requested the informed consent of the parents for the participation of each child. In addition, the participants were identified using pseudonyms, in which their gender but not their real names were maintained. The fictitious names began with the letter of the group to which each child belonged.

2.2. Data Collection

The natural phenomenon that was proposed to the participants in this study was the idea of burning a candle inside an inverted glass vessel. This experiment was chosen for two main reasons. On the one hand, in early childhood education, contents related to facts that are perceptible by the children and that are present in their daily lives must be addressed [50]. On the other hand, Löfgren and Helldén [51] have suggested that the ability to use the scientific concepts concerning matter and its transformations in order to interpret everyday phenomena is an essential goal in compulsory science education.

In order to collect the data, a Predict-Observe-Explain (POE) teaching strategy was designed [52]. The protocol followed was as described below. Firstly, the researcher presented the phenomenon to the children, telling them that a lit candle was going to be covered with a glass and asking them to make predictions as to what might happen. They were also asked to provide their reasoning behind their predictions. Once the children had written or drawn what they thought was going to happen on the questionnaire, the researcher performed the experiment in front of the children so that they could observe the changes that were taking place. In this stage, the researcher guided the children to help them make relevant observations that they had not considered. Finally, the researcher asked the children to record all of their observations on the questionnaire, as well as an explanation of what had happened.

Because of their young age, many of the participants did not have the sufficient skills to be able to write, so the majority of the answers recorded on the questionnaires were in drawing format. To obtain more insight into the children's drawings and make their ideas explicit, the researcher asked them questions while performing the experiment. These dialogues were recorded on audio and video files, which were subsequently transcribed. The video recording was necessary in order to unequivocally identify the intervention of each participant, as well as to capture how the children interacted both with the learning material and with their classmates. As a result, the richness of the data was found predominantly in the discourse of the group guided by the researcher, and not in their responses to the questionnaire. The excerpts that are included in the results section have been translated from Spanish and Galician.

2.3. Data Analysis

We have chosen the explanations provided by the young children as the unit of analysis. According to Christidou [30], an explanation can be defined as 'a coherent segment of an interview accounting for an object's or a substance's behaviour, or a mechanism underlying a phenomenon' (p. 22).

The participants' explanations about combustion were analysed, taking into account some classification frameworks that have been developed in previous studies that aimed to categorise young children's explanations of natural phenomena belonging to other conceptual domains [27,30,32]. In the analysis tool that was adopted, the young children's explanations were divided into scientific, synthetic, naturalistic, and non-naturalistic explanations. Scientific explanations are those that include ideas compatible with the current state of scientific knowledge [32]. Synthetic explanations contain elements that are consistent with scientific knowledge, but that also incorporate some alternative conceptions [32]. Naturalistic explanations are rational and objective, and they reveal an incipient understanding of physical causality [27,30]. If a naturalistic explanation involves the intervention of an external agent that participates in the phenomenon causing the change, this is referred to as agentive. Otherwise, if the internal properties or actions of the substance or object itself are the ones that trigger the change, the naturalistic explanation is referred to as non-agentive. Non-naturalistic explanations can be teleological, intentional, or metaphysical [27,30]. Teleological explanations assume that natural phenomena occur to fulfil a specific purpose. Intentional explanations define animist thinking and attribute intelligent and conscious nature to inanimate entities. Metaphysical explanations attribute the occurrence of natural phenomena to supernatural powers or divine entities.

In order to facilitate the understanding of the analysis tool used in this paper, each type of explanation is illustrated in Table 1, with examples described from previous research. We have not provided any examples of the combustion phenomenon due to the lack of studies in the field of chemical reaction in early childhood education.

To ensure the validity of the qualitative analysis and provide a certain degree of triangulation, the children's explanations were coded by the authors independently [48]. By comparing the authors' coding, an 89% level of inter-rater reliability was achieved.

Table 1. Types of young children's explanations about different natural phenomena reported in previous studies and listed considering the desirable knowledge: from the lowest (non-naturalistic explanations) to the highest (scientific explanations) level of sophistication.

Types of Explanations	Examples
4. Scientific	Rainwater evaporates and becomes a cloud when it condenses [32].
3. Synthetic	Clouds are made of snow and bring water. Fallen rainwater mixes with seawater and the snow falls and returns to clouds [32].

Table 1. *Cont.*

Types of Explanations		Examples
2. Naturalistic	Agentive	Why can't you see the sugar now? It went down into the water and when we stirred it, it broke [30].
	Non-agentive	Why did the marble go down? Because it is heavy. [. . .] It is made of iron [30].
1. Non-naturalistic	Teleological	How come it rains? It rains because the plants need to be watered [30].
	Intentional	Why does it float [the cork]? Because it is very careful. [. . .] It keeps its eyes open [30].
	Metaphysical	Where does the rain come from? It comes from God. God pours water from the sky [30].Why does the paper clip stick onto the magnet? Because it's [the magnet] got glue on it [30].

3. Results

Table 2 shows the types of explanations that were given by the children, making a distinction between group A and B. It is worth mentioning that the number of explanations exceeds the number of participants because some children produced more than one explanation throughout the different phases of the experimental task. To contrast how each child's answer evolves from the prediction to the conclusion phase, Table 2 includes both the frequency and the name of the children whose response fits into each category of explanation.

Table 2. Children whose explanations fit into each category and frequency of each type of explanation: group A (N = 8) and group B (N = 14).

Types of Explanation		Prediction Phase		Conclusion Phase	
Group A (N = 8)		Students	f	Students	f
Scientific		-	0/8	-	0/9
Synthetic		-	0/8	-	0/9
Naturalistic	Agentive	-	0/8	Alberto, Alexandre, Andrea, Amanda, Aurora, Alicia	6/9
	Non-agentive	Alberto, Adrián, Alexandre, Andrea, Amanda, Aitana, Aurora	7/8	Adrián, Aitana, Aurora	3/9
Non-naturalistic	Teleological	-	0/8	-	0/9
	Intentional	Alicia	1/8	-	0/9
	Metaphysical	-	0/8	-	0/9
Group B (N = 14)		Students	f	Students	f
Scientific		-	0/14	Belinda, Benjamin	2/15
Synthetic		Beatriz, Blanca, Belinda, Berta, Brenda, Borja, Balbino, Baltasar, Benedicto, Boris	10/14	-	0/15
Naturalistic	Agentive	Blas, Bernardo, Bruno, Benjamin	4/14	Beatriz, Blanca, Berta, Brenda, Borja, Balbino, Baltasar, Benedicto, Boris, Blas, Bernardo, Bruno, Benjamin	13/15
	Non-agentive	-	0/14	-	0/15
Non-naturalistic	Teleological	-	0/14	-	0/15
	Intentional	-	0/14	-	0/15
	Metaphysical	-	0/14	-	0/15

In the prediction phase, in which the young children were asked what they thought would happen if a lit candle was covered with a glass vessel, most of the participants in group A provided naturalistic explanations that did not involve the intervention of an external agent. The children of preschool age predicted that the candle would explode, melt, or emit light just because it was a lit candle, as we can see in the following excerpt:

Researcher: 'What do you think will happen when the candle is lit, and a glass is placed on top of it?'

Alberto: 'It will melt'.

Researcher: 'Why?'

Alberto: 'Because what is inside melts.'

One girl in group A constructed an intentional non-naturalistic explanation, by attributing characteristics inherent to a human body, such as a heart to the candle.

Researcher: 'Alicia, what do you think is going to happen?'

Alicia: 'The candle is going to turn orange, yellow and red, because then it will come out like a heart.'

Most children in group B made synthetic predictions. Seven children of preschool age mentioned that a condensation process was going to take place on the walls of the glass, but they thought that the substance that was going to be condensed was smoke or droplets that came from the candle. The last fragment of the prediction is inconsistent with the scientific explanation of the phenomenon, given that the substance that is condensed is the water vapour which is released during the combustion of paraffin or wax. As an example, we have included the following excerpt from the transcribed discourse:

Researcher: 'We have a candle, we are going to light it, and then cover it with a glass [. . .]. You have to think about what is going to happen.'

Beatriz: 'There is condensation on the glass. Because when the droplets are so hot due to the fire, they may also condense [. . .]. A candle . . . a glass that covers it . . . and this is what is tarnished [talking as she explains her drawing].'

The other three children whose predictions were ascribed to the synthetic category referred to the fact that the candle would go out, since it was cold inside the glass, as shown in the excerpt below:

Blanca: 'Perhaps the candle that is lit will go out because it (the glass) is very cold.'

Researcher: 'Why will the candle go out?'

Borja: 'Because the cold can extinguish anything.'

From a scientific perspective, the flame is extinguished due to a decrease in the amount of oxygen inside the vessel. However, it is worth mentioning that it was not expected that the young children would make a spontaneous reference to the fact that the candle would go out, and it is important to remember that these children had not received specific prior instruction on combustion.

Four young children's predictions were coded as agentive naturalistic explanations, given that their responses referred to the idea that the candle would set fire to or melt the glass that covered it due to the intervention of an external agent (the fire), as can be observed in the following example:

Blas: 'The candle will burn the glass because the glass is made of iron and the candle will burn it [. . .]. In a cartoon that I saw, the lava from a mountain fell on some cars, and they put iron and the lava destroyed it.'

Researcher: 'But the vessel that we are going to cover the candle with is made of glass.'

Blas: 'But it can melt too.'

After performing the experiment, all of the children observed how the candle went out. Moreover, sixteen of the children noticed that the glass was tarnished, however their interpretations varied depending on which group they belonged to. In group A, four of the children thought that the glass had become foggy, however they did not provide any further explanations for this, with one child mentioning that the fire had stained the glass. Eleven of the children in group B related mist formation with water vapour, or with drops coming from the flame, or more generically, from the candle. Previous experiences during their schooling, including their participation in a science project about the water cycle, helped this group of children to easily identify water vapour.

In the conclusion phase, when the researcher asked the children why the candle had gone out, six of the children in group A gave agentive naturalistic explanations. Most of them mentioned that the candle had gone out because there was a cloud inside the glass and it was very windy, as indicated in the following example:

Researcher: 'Now can you explain your drawings?'

Alicia: 'There was a cloud inside the glass and it was very windy, and the candle went out.'

Amanda: 'Because it [the glass] has no outlet and there was wind inside, it extinguished the candle.'

In group B, most of the children provided agentive naturalistic explanations. Similar to the prediction phase, five children mentioned that the candle had gone out because of the cold temperature inside the vessel, and two of the children claimed that it was caused by moisture. Six children pointed out that the candle went out because there was air inside the vessel, as indicated in the following example:

Researcher: 'And why did it go out?'

Blas: 'Because there was air inside.'

Researcher: 'And is there no air in here [in the classroom]?'

Bruno: 'Yes, but here [in the classroom] you do not really know where it is because the air moves much more.'

One explanation, which is particularly worth mentioning was given by a girl, Belinda, from group B who explained the phenomenon consistent with the scientific idea that air is required to maintain combustion. She mentioned that the candle had gone out because there was no air entering the vessel. This explanation was triggered by a question asked by the researcher that made her rethink the reason why the candle did not go out when it was uncovered.

Researcher: 'Why does it not go out when I do not cover it? You can see that candles stay lit for a long time when they are not covered.

Belinda: 'Because there was no air coming in.'

During the activity, another child, Benjamin, expressed a similar idea, indicating that the candle had gone out due to the lack of oxygen in the glass. However, due to the influence of his classmates, he replaced this scientific explanation with an agentive naturalistic explanation.

In Table 3, we included the elements of explanation to which students referred in their answers both during the prediction and the conclusion phase. As show in Table 3, some children maintain the same response along the teaching sequence. This happens when there is not a disagreement between the empirical data and the original children's prediction. A sort of cognitive conflict between observations and what children expected to happen favor the development of ideas [18].

Table 3. Elements of explanation to which students referred in their answer during the teaching intervention and frequency of each element of explanation: group A (N = 8) and group B (N = 14).

Categories	Prediction Phase		Conclusion Phase	
	Students	f	Students	f
A condensation process takes place on the walls of the glass.	Beatriz, Berta, Brenda, Baltasar, Benedicto, Boris, Belinda	7/22	-	0/24
The candle explodes.	Amanda	1/22	-	0/24
The candle melts.	Alberto, Adrián, Alexandre, Andrea	4/22	Alberto, Alexandre	2/24
The candle changes color, and a heart comes out.	Alicia	1/22	-	0/24
The candle emits light.	Aitana, Aurora	2/22	-	0/24
The glass burns or melts.	Blas, Bernardo, Bruno, Benjamin	4/22	-	0/24
Stain appears on the glass.	-	0/22	Adrián, Aitana, Aurora	3/24
The candle goes out because of the cold temperature.	Blanca, Borja, Balbino	3/22	Blanca, Borja, Balbino, Berta, Brenda	5/24
The candle goes out because there is air/wind inside the vessel.	-	0/22	Alicia, Amanda, Aurora, Andrea, Blas, Bernardo, Bruno, Benjamin, Benedicto, Boris	10/24
The candle goes out because of the lack of oxygen/air.	-	0/22	Benjamin, Belinda	2/24
The candle goes out because of moisture.	-	0/22	Beatriz, Baltasar	2/24

4. Discussion

Regarding the first research question that aimed to identify the type of explanations used by children when reasoning about combustion, the results revealed that most children tend to give naturalistic explanations in which an incipient understanding of physical causality is evident. However, the characteristics of these explanations were different throughout the experiment. During the prediction phase, the young children's explanations were mainly non-agentive in group A. Seven children in this group indicated that the candle would melt or explode based on the internal properties of the changing object itself. However, the participants' predictions were mainly synthetic in group B, referring most of them to a condensation process on the walls of the glass. During the conclusion phase, children's explanations were predominantly agentive considering both groups. When explaining why the candle went out when it was covered with a glass, most of them included the action by agents such as moisture, air, or the wind. From previous experiences in their daily lives, the children were aware that a candle's flame is often extinguished by blowing on it, therefore their immediate intuition led them to think that the fire was extinguished by the air. Interestingly, no metaphysical or teleological explanations were recorded in either of the two groups. This result differs from that of previous studies on other natural phenomena in which it was determined, for instance, that young children explain the attraction of a paper clip in metaphysical terms, considering the intervention of magical powers [30].

The construction of naturalistic explanations by young children is highly important, given that this demonstrates that they are capable of constructing representations that can be considered as precursor models [5]. In this study, the results showed that most of the children explained the combustion of a candle in naturalistic terms, without restricting their explanations to animism, metaphysics, or teleology. Therefore, it is clear that the children who provide these kinds of explanations are able to construct a precursor model in the domain of matter and its transformations. It even seems that some of the children in group B were already able to construct a precursor model based on previous learning experiences, such as those related to the water cycle. Some of these children were able to associate condensed water with the water vapour that was released during the combustion, and thanks to the observations and the challenging questions posed by the researcher, two of the children were able to explain that the candle went out due to a lack of oxygen.

On the other hand, the results showed that one girl in group A gave an intentional non-naturalistic response during the prediction phase. However, among children who were used to performing inquiry-based activities in which they were asked to interpret everyday phenomena, we do not observe non-naturalistic explanations. Moreover, those children who were used to doing inquiry-based activities gave more sophisticated responses during the prediction phase and some of them are even capable of providing construction explanations that incorporate incipient ideas about science after observing the phenomenon. Interestingly, thanks to the challenging questions posed by the researchers, two children in group B were able to conclude that the candle had gone out due to the lack of air or oxygen. This response was not expected of children in this age group, since previous studies have found that not even primary or secondary students mention the need for oxygen or air for the combustion [45]. Regarding whether experience doing science activities may impact on the young children's construction of explanations, based on the data, it is not clear enough that it has a benefit on the ability to interpret natural phenomena, given that in the conclusion phase (after the teaching intervention), there was no significative difference in the performance of both groups. Most of the young children in group B (13/15) made naturalistic explanations like children in group A (6/9). Further investigation around this topic is necessary. Further, the qualitative nature of this study involving a small sample size does not allow to generalise results and conclusions, but it allows for comparison with other studies of similar nature.

5. Conclusions

The results related to the experiment involving burning a candle inside a glass revealed that young children are able to handle naturalistic explanations, even without prior formal instruction on the topic of matter and its transformations. This finding is relevant for science educators and those entrusted with the task of designing curricula, given that the conceptual fields in which young children are able to provide naturalistic explanations seem to be appropriate for stimulating the development of children's causal reasoning during the preschool years [27]. Moreover, this study confirms that young children are capable of making predictions and reaching simple conclusions based on their observations, even though these may not be scientifically accurate or complete [32]. All of these results can be considered as indicators that young children are able to develop a precursor model of the concept of matter, which enables them to predict and explain different phenomena. This precursor model can be built on and expanded through relevant science activities in which suitable empirical data are provided [5]. Inquiry-based activities that require children to ask questions and provide explanations seem especially appropriate. These activities move away from the explanation-application format in which the information is first given and then applied to solving problems, and which make it difficult to develop models [53].

Our findings also indicate that when children are used to performing inquiry-based activities, it is more likely that they are able to establish relationships with previous experiences in order to explain the observed events. Probably thanks to their participation in activities related to water cycle, most of the participants in group B were able to identify the water vapour released during combustion. These findings reinforce the importance of introducing science activities in early childhood education [3]. However, at this stage of schooling, not all science activities offer the same potential. Science teaching in early childhood education must be organised around the choice of contexts that are familiar to young children, which allow them to think, ask questions, and construct explanations [54]. In addition, it is important to bear in mind that young children's learning is physical and practical rather than conceptual, therefore meaning that they learn by being in contact with their environment [55].

As final considerations, it is worth mentioning again that due to the qualitative nature of this study, which involved a small sample of children, further research must be conducted in order to expand on the existing knowledge about young children's conceptions of matter and its transformations, and also to confirm the hypothesis that they are capable of forming a precursor model in this domain.

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Article

Study of Kindergarten Teachers' Intentions to Choose Content and Teaching Method for Teaching Science

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Abstract: In this paper, we investigate the intentions of kindergarten teachers to use the content and to apply the teaching methods that they acquired in a one-day teacher training seminar. According to the theory of planned behavior, the answer to this research question is directly related to a series of social-psychological personal criteria assessments, such as an assessment of the personal gains or losses, the opinions of important third persons, the teacher's own assessment of the value of the students' learning, and the perceived behavioral control assessment. A total of 114 participants completed a 5-point Likert-scale questionnaire that consisted of two sets of five questions each. The results show that the kindergarten teachers' intentions to use particular content and teaching methods are based on whether they have the skills to apply them successfully, and on their assessment of the ability of their students to acquire meaningful knowledge. The teacher's choice of teaching method is also associated with the assessment of the personal gains or losses, as well as with the opinions of important third persons. Furthermore, the study findings show that there are two distinct categories of kindergarten teachers: those whose teaching is based on the tradition of science education, and those whose teaching is based on the tradition of early childhood education. The teaching implications of the results are also discussed.

Keywords: science education; early childhood education; discovery demonstration and inquiry-based teaching methods; theory of planned behavior; kindergarten teacher training

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1. Introduction

The recommendation that the natural sciences, which include physics and biology, be taught in kindergarten is based on a number of reasons [1] that form a set of science teaching objectives. These objectives are associated with the following:

1. The pupils' development of a positive attitude towards science, starting from their inherent curiosity to observe and wonder about the natural world;
2. The positioning of kindergarten science teaching as the precursor to a better understanding of scientific content and concepts through the pupils' exposure to the scientific approaches to phenomena, and to the use of scientific terms to describe them; and
3. The positioning of kindergarten science teaching as the basis for the cultivation of scientific thinking and its justification.

Kindergarten teachers have undergone studies with regard to, and have experience and knowledge of, a satisfactory range of knowledge in terms of the pedagogical, psychological, and social management of children [2]. However, their knowledge is rather limited in terms of the scientific content and the practices of science [3]. In Greece, the studies on early childhood education, on the corresponding curricula [4–7], and on the guide for kindergarten teachers [8], focus on the pedagogical and developmental goals for children in early childhood education, where the daily teaching program consists of relatively autonomous and short-term activities. In addition to relaxing and fun activities, the science-based exercises are generally based more on empirically established routines (e.g., playing, drawing, discussing, watching the teacher's demonstrations or listening to narratives, etc.) rather than on the content.

These activities are also focused on the goal of constructing more everyday experiential knowledge about the natural world, rather than on scientific knowledge [4,9,10]. However, the abovementioned teaching/learning objectives [1] raise issues within the teacher–pupil relationship that are related to aspects of science—and to the ways in which these aspects are taught—that may not conform to the above pedagogical tradition for a number of reasons:

1. It is expected that pupils develop positive attitudes and views towards science on the basis of those held by their teachers [11]. These attitudes and views have been acquired by teachers as lay adults, rather than as professionals who are trained in science;
2. The pupils' understanding of the content, which has inevitably been transformed didactically, is directly related to the science education issues of various subject areas (e.g., physics, chemistry, biology) that usually focus on the different structures and natures of the subject contents, and on the related teaching methods. These subject contents and teaching methods are, in practice, more likely to be transformed by the teachers' own general pedagogical views and goals, than to be used on the basis of the contemporary didactics of the various subject areas;
3. Scientific thinking and its justification are based on the structure of recognized scientific practices [12]. In this way, they tend to be inconsistent with the dominant narrative discourse in early childhood education, which often guides thought and explanation teleologically, or suffices to recognize the causes of individual events, which are simply ordered in time [13]. This is a discrepancy that kindergarten teachers (who, from their pedagogical education, have learned to work primarily with an inductive type of methodology) have been asked to manage.

The above three reasons correlate: (a) The positive attitudes that pupils should develop towards science with their kindergarten teachers' approaches to the nature of science; (b) The pupils' understanding of the content with the teaching methods that are implemented by the teachers; and (c) The scientific practices that the teachers are expected to teach with the forms of speech that they adopt when teaching their students about scientific thinking and argumentation. These correlations are to be striven for by professional kindergarten teachers, who should change, or rearrange, some of their established practices. Questions arise as to whether a simple process of teacher training is sufficient to overcome these difficulties, and as to whether this process should take into account additional important variables that should be adjusted accordingly, such as those that emerge within the dynamics of their profession [14].

In this paper, on the basis of the discussions that took place at a one-day teacher training seminar on the teaching methods for physics and biology, we attempted to investigate the intentions of kindergarten teachers to use the content of these two science subjects, as well as the particular method, discovery demonstration and/or inquiry-based, that they applied in their teaching practice. The aim was not to evaluate the effectiveness of the seminar, but rather to identify any modifications and improvements that could be made.

2. Research Framework, Questions, and Hypotheses

The study involved 114 kindergarten teachers, who voluntarily attended a one-day teacher training seminar on the issues that were being discussed and developed in the fields of physics and biology education. These issues were concerned with the understanding of both the subject contents and the relevant teaching methods, the cultivation of scientific discourses and practices, as well as with assessing whether the knowledge that is learned by pupils is considered meaningful (attitude).

The seminar consisted of two parts of approximately equal durations (6 h in total): brief theoretical lectures, which were followed by workshops on the science teaching issues that were relevant to both the subject contents and the practices [15]. The topics covered were: "Didactic Transformation of Physics' Content and Inquiry: Applications in kindergarten education"; "Difficulties in managing elementary biological concepts in kindergarten education"; and "Control of variables strategy in kindergarten education". The purpose of the short lectures that preceded the workshops was to present to and prepare the kindergarten teachers on: (a) The basic concepts of science education, such as the didactic transformation of the content, and the ideas and difficulties of children in understanding the concepts and processes of physics or biology; and (b) The corresponding scientific procedures and/or practices (inquiry, the control-of-variables strategy, etc.), which were conducted only for the physics content because of time constraints.

Specifically, in the theoretical sessions about biology, the teachers were given to understand the difficulties that exist in the comprehension of the terms used, as well as in the general misconception in the wider society with regard to biological concepts, processes, and practices (e.g., evolution, ecological relations, environmental problems). In the workshop sessions, in pairs or groups of three, the participants worked through the issues from a worksheet, which was discussed afterwards in plenaries. The worksheet was used to guide the pair/group discussion. The focus was on the types of speech used by kindergarten teachers, which, on the one hand, could give rise to or foster the pupils' misunderstanding, and, on the other, could, in itself, be laden with personal values that may unintentionally be imparted to the pupils. The teachers also performed exercises on confronting the children's difficulties and misunderstandings, with an emphasis on the presentation and discussion of the concepts and processes (the content issues).

Specifically, in the theoretical sessions about physics, the teachers were introduced to two teaching approaches: the "discovery demonstration" and "inquiry-based" teaching methods. In each case, emphasis was given to the content management in relation to the teaching processes and the relevant scientific practices. The examples that were given demonstrated the scope of each teaching approach and pointed out their differences. In the workshop sessions, the teachers were given the opportunity to investigate specific physics concepts (e.g., floating/sinking phenomena, static electricity, friction, etc.) through the application of both methods. With the "discovery demonstration" approach, the physics issues were examined by using experimental procedures that followed the "predict–observe–explain" model [16], while, at the same time, simple questions were applied (e.g., "Why do bodies float?", and "What is it that makes one body float while another sinks?"), the answers of which involve only one factor. In the "inquiry-based" approach, the physics issues were examined by using experimental procedures that were based on the use and understanding of scientific reasoning as a way of teaching the control-of-variables strategy, while open-ended questions were applied, the answers of which consisted of more than one factor [17], which created a more complex framework for solving the problem. (An example of this type of problem is, "One of your classmates claims that heavy objects sink. Can you suggest an experiment to check this assumption?") An important feature of the inquiry-based approach is that, in addition to the experiments that can lead to safe conclusions, the experiments that did not meet this condition were also discussed, either because other variables apart from the one being studied were changed, or because there was no change to the variable under study in two trials of an experiment. One of the seminar's main goals was to show that the inquiry-based learning method, through the control-of-variables strategy, is an innovative and effective method for early childhood science teaching. More specifically, the aim was for kindergarten teachers to understand certain aspects of the CVS method itself; to be aware of the difficulties in understanding and implementing the method, not only for themselves, but also for their pupils; and to recognize and accept that it is an important method to understand and apply, even for kindergarten-aged children.

The inherent question that arose in the training seminar was whether the teachers would apply the didactic issues that were discussed when they returned to their classes. It was hypothesized that the answer to this question would differ in accordance with:

- The content (C) being categorized into either that of physics or biology;
- The teaching methods (TMs), either discovery demonstration (DD) or inquiry-based (I-B), which were analyzed and made distinct for the physics content;
- The teachers' beliefs about the content (physics or biology) and the teaching method (DD or I-B) to be used in terms of the pupils' ability to acquire meaningful knowledge (SL).

According to the theory of planned behavior [18–20], the answer to this research question (i.e., the kindergarten teachers' intentions to choose the subject content and to use specific teaching methods) is directly related to a series of social-psychological personal criteria.

More specifically, the teachers' intentions (in other words, their behavioral intentions (BIs)) to engage in specific ways and with specific actions in their future teaching practices are related to:

A. The assessment of their personal gains or losses: the attitude (AT) criterion;
B. The assessment of the views of third persons who are important to them: the subjective norm (SN) criterion;
C. The assessment of their personal competencies with regard to the control of, "what do I do in teaching": the perceived behavioral control (PBC) criterion.

Finally, because teachers seem to choose what they will teach on the basis of the value that they estimate it has to their pupils' learning [21,22], we assumed that the intentions of the kindergarten teachers would also depend on the following variable:

D. Whether the pupils learn meaningful knowledge from the content that they are taught, or from the way that they are taught it (SL).

Therefore, the research questions are as follows: Do the teachers' intentions differ when they opt in favor of physics or biology content in their classrooms? Do the teachers' intentions differ when they choose between the discovery demonstration and the inquiry-based learning methods to teach physics content? To what extent do these differences depend on the teachers' assessments of their personal gains or losses (AT), on the positive or negative opinions of important third persons (SN), on the assessments of their perceived ability to control (PBC) the teaching process, and on their assessments of how much meaningful knowledge the children eventually learn (SL). These questions are schematically represented in Figure 1.

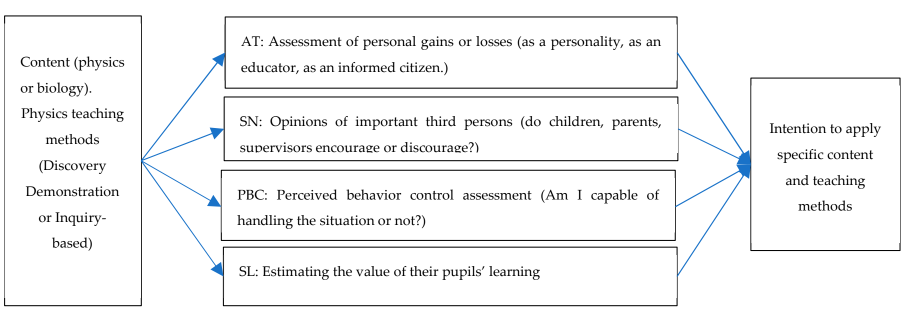

Figure 1. The factors that influence teachers' intentions to apply specific content and teaching methods.

The answer to these questions may enable us to devise and test the modifications in early childhood science education that will trigger educational discussions, starting with the subject contents (nature, teaching, learning) and the teaching methods, that will have an impact on the professional culture of kindergarten teachers.

More specifically, we assume that the intentions of kindergarten teachers to apply activities with science content is indirectly influenced, in a complex way, by the teachers' views on: (A) The content to be taught; and (B) The relevant teaching methods.

In terms of the content to be taught (A), the teachers share the public's perceptions towards the scientific content that has pervaded society and the daily lives of citizens, in addition to having been shaped by their general and professional education.

Internationally, the so-called "exact" sciences (mathematics, physics, and chemistry), while they are considered difficult to grasp, are still highly regarded as valuable by the general public [23]. On the other hand, biology, which, since the end of the 20th century has been considered a complex science, is becoming an emerging science in the wider community [24]. Biology is the science that raises the issues that are extremely important to our society (such as health, ecology, etc.). Consequently, biology acts to fuse, on the one hand, the relationship between the public understanding (see "scientific literacy") and the appreciation of science and scientists [25,26], and, on the other hand, the relationship between the public acceptance of scientific views and the functioning of democracy [27]. The educational value of both of these issues has been highlighted, beyond any doubt, by the current pandemic.

Generally, in education, the images of these sciences, which make strong associations between science and society, have remained more or less constant since the 1960s [24]. Although the sciences are considered to be cognitively difficult subjects, they are, nevertheless, deemed interesting (with biology, it seems, as the most interesting) [24]. In many societies, these science subjects are mainly thought to be more popular with, and useful for, boys, while biology is considered useful for girls as well. Biology, therefore, seems to be one of the most popular courses among students generally [24], and students hold very positive attitudes towards this school subject [24].

Thus, we assumed that the intentions of teachers to choose to teach the contents of either physics or biology (or both) for their lessons would be influenced by two factors: one is related to how "difficult" the subject matter is, and the other is related to the "utility" of the subject matter. With regard to the subject's difficulty, we assumed that teachers would assess this on the basis of their perceived behavioral control (PBC) skills and on the student learning (SL), whereas, with regard to the subject's usefulness, we assumed that this would be assessed mainly on the basis of the student learning (SL). Additionally, we expected that kindergarten teachers would be likely to differ in their intentions to choose content from physics or biology, as the perceived difficulty of physics, and the perceived usefulness of biology, may influence their assessments of the personal gains or losses (AT), as well as those of the opinions of important third persons (SN).

In terms of the teaching—and learning—of sciences (B), kindergarten teachers are in a position where they are required to deal with two relatively different educational traditions, that of early childhood education and that of science education [28]. However, the kindergarten teachers in Greece attempt to teach physics or biology without possessing sufficient content knowledge of either subject [29–31]. Furthermore, the kindergarten teachers' knowledge and experience are inadequate with regard to the use of scientific models to describe and explain real natural systems [32], and to the use of scientific practices and argumentation [33,34]. They are, it seems, fully aware that teaching some of these scientific models and practices is a professional obligation, as it is part of the early childhood education curricula in Greece. It has been shown, however, that the frequency with which such approaches are incorporated into their teaching does not depend on either the teachers' experiences or the curriculum [21]. Thus, it would be safe to assume that the kindergarten teachers' intentions to include scientific content and practices in their everyday teaching are strongly influenced by the traditions of early childhood education and science education, as well as by their personal teaching approaches.

One would expect that those teachers who are more dependent on early childhood learning approaches would not differentiate between the contents of physics or biology, and that they would adopt general pedagogical practices in teaching this subject matter, as they would any other. These pedagogical practices are implemented in a natural language and are evaluated as effective if they follow narrative structures [13,35–37], or if they connect narratives with paradigmatic and experiential evidence [38]. There are indications [39] that this general pedagogical approach, which transforms the content through a science narrative and "transfers" the scientific models to students (sometimes successfully and sometimes not), is used widely by teachers. We find it in the texts of children's books on science that are published in abundance, and that are also distributed in schools. For example, in Greece, there is a wide variety of books, games, and toys for children that present and explain scientific issues, most of which are translations from other languages.

In the early childhood educational approach, the contents of the various science subjects are presented in simplified narrative language structures, in contrast to the older classes of primary school, where this content is mainly transferred through formal language structures.

Thus, in the results of the research, we would expect that there would be a significant number of kindergarten teachers who would not discern any differentiation in their intentions to apply one or the other of the two teaching models (DD or I-B). This is despite having participated in the training seminar, where they had recently had the two teaching methods, within the framework of the content of a single science subject (physics), presented to them and discussed.

In contrast, we expected that the teachers who focused more on the didactic approach of science education, which they learned in their undergraduate and/or postgraduate studies, as well as in the seminar that is covered in this study, would exhibit individual differences in their intentions as to the teaching method that they chose to apply. The source of these differences is considered to lie in the so-called "disunity of science", in the educational context [40]. The extensive range of topics in the fields of physics and biology that are proposed for the curricula display fundamental methodological and epistemological differences [41], which cannot be ignored in the didactic approach taken. For example, certain aspects of the experimental practices that are implemented with the objective of demonstrating the scientific confirmation of established conceptual models of physics are taught without regard to the teaching method. These aspects, depending on the teaching method that is applied, are used to generate conceptual conflict, to demonstrate evidence that guides the students' "discovery" of a conceptual model, or to explore the dynamics of a system in order to reinforce that the students' initial views are compatible with scientific ones, and so on.

These experimental practices cannot, however, be applied to the teaching of the classical models of biology, where the systems that are studied are open and are, therefore, complex, self-organized, and historical [41]. For instance, it is not possible to design experiments that demonstrate how things or processes evolve on the basis of the dynamics of the conceptual models of biology within the teaching time that is available. Although snapshots of the evolutions of the systems to be taught/learned can be observed (with photographs or a microscope), and field research can be organized, it is impossible for experiments that represent the dynamics of evolution, climate change, heredity, reproduction, genetics, and ecosystems to be presented in the school classroom or science lab, or to be conducted in vivo. Thus, it seems that both the conceptual conflict and discovery demonstration methods are rather weak approaches for biology education. This is why we consider that, from the teaching methods that are used in physics, only inquiry-based learning is effective for biology education. The field research also proposes this method as a didactic approach to biology [42].

Thus, in the results of this study, we would expect a significant number of kindergarten teachers who are more influenced by science education to state that their intentions would be to apply both of the teaching methods (discovery demonstration and inquiry-based) that were presented in the seminar on physics. We expected these preferences to be indiscriminately influenced by all of the variables of our model. More specifically, we expected the teachers' assessments of their perceived ability to control (PBC) the application of the teaching methods, and those that refer to how much meaningful knowledge the students learn (SL), to be dominant (e.g., "I choose the discovery demonstration or inquiry-based teaching methods because I can apply them successfully, that is, I can apply them in a way that students would learn" (success criterion). In addition, we also expected that the teachers' assessments of their personal gains or losses (AT), as well as those that refer to the opinions of important third persons (SN), would have positive influences on the results (e.g., "When I teach successfully, I feel good in the classroom, and important third persons would approve"). Finally, we expected that the kindergarten teachers who chose the biology content would be more likely to choose the inquiry-based teaching method for physics on the basis of their assessments that they can also successfully teach physics with the I-B approach in the same way that they used it to teach biology (PBC).

3. Methodology

After the conclusion of the seminar, the 114 participants completed a 5-point Likert -scale questionnaire, which was divided into two sets of items (see Appendix A). In each of the sets of questions, the first item focused on investigating the teachers' intentions to choose the contents and the teaching methods that were discussed during the seminar. Specifically, the first item of the first set focused on investigating the intentions of the teachers to choose the content for their teaching from the two distinct scientific areas (physics or biology), and the first item of the second set focused on investigating their intentions to choose a teaching method (discovery demonstration or inquiry-based) when using the physics content, as the seminar focused on the teaching methods only for the physics content. In the second item of each set of questions, the teachers assessed the value of the students' learning outcomes (SL: student learning), depending on the physics or biology content (for the first set of questions), or on the teaching method that they adopted (discovery demonstration or inquiry-based, for the second set of questions) when they implemented the physics content. The last three items in each set of questions investigated the teachers' planned future actions, according to the theory of planned behavior [18–20]. Specifically, the three variables that were examined were the teachers' assessments of: (a) Their personal gains or losses (AT: attitude); (b) The opinions of important third persons who approved or disapproved of their behavior (SN: subjective norm); and (c) Their ability to control the teaching process (PBC: perceived behavioral control).

No demographic data were included in the questionnaire, as the participants made up a relatively homogeneous sample: they were all women with more than 5 years of teaching experience, and who were all teaching in the same geographical area (Florina, Western Macedonia, Greece).

Finally, the reliability/internal consistency test on the answers to the questionnaire [43,44] produced significantly different values for the Cronbach's alpha coefficient in the two distinct sets of questions. The value related to the first set of questions (the content choice intention) was ac = 0.542, whereas the value related to the second set of questions (the teaching method choice for physics) was atm = 0.760. We thus proceeded with our analysis while bearing in mind that our data reflected the fact that the views of the teachers were internally consistent mainly with regard to the teaching method choices, and less with regard to the issue of the content choice.

The data were analyzed following:

1. A descriptive analysis, in terms of the main research questions of the study, with the aims of, first, investigating the kindergarten teachers' intentions to choose specific content (physics and/or biology) and to use specific teaching methods (discovery demonstration and/or inquiry-based) when they teach physics, and second, investigating the teachers' assessments about whether their pupils acquired meaningful knowledge from the content (physics and/or biology) from what they were taught, or

from the way they were taught (discovery demonstration and/or inquiry-based), in terms of the physics content;

2. A factor analysis of the teachers' responses in order to investigate if there are specific ways of thinking when the teachers choose content or a teaching method. The results of this analysis might offer interpretations as to the differences in the values of the Cronbach's alpha coefficients in relation to the different possible ways that teachers think;
3. A linear regression analysis on the variables of the theory of planned behavior and the assessments of the student learning (SL), which, according to our theoretical model, determines the kindergarten teachers' intentions to choose a specific subject's content or a teaching method. This analysis is focused on investigating the weight and the significance that each variable of our theoretical model had on the teachers' thinking when they chose the content or the teaching method.

4. Results

4.1. Descriptive Analysis

With regard to the teachers' intentions to use physics or biology content in their lessons, and to their intentions to use the descriptive demonstration or the inquiry-based method when teaching physics, the results show (Tables 1–3) that, through their choices, all of the possible combinations of both of these factors came up (Table 1). Please note, that the teachers' responses for both sets of questions in Tables 1–3 correspond to an aggregate percentage of "only" and "mostly" choices on the Likert scales. As can be seen in Table 1, the highest total percentage (66.7%) was the teachers' intentions to use both physics and biology content equally in their lessons, and by using the two method choices. In addition, there is a significantly higher total percentage for the teachers' intentions to teach the physics content with both or either method (26.3%), in contrast to their intentions to teach the biology content with either method, with a total of just 7%.

Table 1. Frequencies/percentages of teachers' choice of content (physics or biology) and teaching method (discovery demonstration or inquiry-based).

Subject Content Chosen by Teachers	Method Chosen byTeachers to Teach Physics	Frequency (Percentage)
Physics	Discovery demonstration (DD) Inquiry-based (I-B) Both DD and I-B equally	8 (7.0%) 3 (2.6%) 19 (16.7%)
Total		30 (26.3%)
Biology	Discovery demonstration (DD) Inquiry-based (I-B) Both DD and I-B equally	3 (2.6%) 3 (2.6%) 2 (1.8%)
Total		8 (7.0%)
Both physics and biology equally	Discovery demonstration (DD) Inquiry-based (I-B) Both DD and I-B equally	18 (15.8%) 19 (16.7%) 39 (34.2%)
Total		76 (66.7%)

Table 2 presents the teachers' assessments on how meaningful the students' learning was in relation to the teachers' choices of either physics or biology content. Three-fourths of the kindergarten teachers (75.4%) assessed that the students' learning was meaningful for both sciences, regardless of their intentions to choose the content (physics, biology, or content from both subjects equally, at 19.3, 3.5, and 52.6%, respectively).

Table 3 presents the teachers' assessments on how meaningful the students' learning was in relation to the teachers' choices of teaching method when the teachers chose to teach physics. In this case, 43.9% of the kindergarten teachers assessed the students' learning of physics as meaningful, regardless of their intentions to choose a specific teaching method (discovery demonstration, inquiry-based, or both methods equally, at 7.9, 4.4, and 31.6%, respectively). In addition, there is a substantial percentage of the teachers who assessed the students' learning of physics to be meaningful only with the discovery demonstration approach (30.7%) or the inquiry-based method (25.7%), regardless of their intention to choose a teaching method.

Table 2. Teachers' assessments of students' learning in relation to content selection.

Teachers' Choice of Content	Subjects Assessed as Meaningful by Teachers in Terms of Student Learning	Frequency (Percentage)
Physics	Physics	8 (7.0%)
	Biology	0
	Physics and Biology Equally	22 (19.3%)
Total		30 (26.3%)
Biology	Physics	0
	Biology	4 (3.5%)
	Physics and Biology Equally	4 (3.5%)
Total		8 (7%)
Physics and Biology Equally	Physics	5 (4.4%)
	Biology	11 (9.7%)
	Physics and Biology Equally	60 (52.6%)
Total		76 (66.7%)

Table 3. Assessments of students' learning of physics in relation to selection of teaching method.

Method Chosen by Teachers to Teach Physics	Method Assessed as Meaningful by Teachers in Terms of Students' Learning of Physics	Frequency (Percentage)
Discovery demonstration (DD)	Discovery demonstration (DD)	17 (14.9%)
	Inquiry-based (I-B)	3 (2.6%)
	Both DD and I-B equally	9 (7.9%)
Total		29 (25.4%)
Inquiry-based (I-B)	Discovery demonstration (DD)	4 (3.5%)
	Inquiry-based (I-B)	16 (14.0%)
	Both DD and I-B equally	5 (4.4%)
Total		25 (21.9%)
Both DD and I-B equally	Discovery demonstration (DD)	14 (12.2%)
	Inquiry-based (I-B)	10 (8.8%)
	Both DD and I-B equally	36 (31.6%)
Total		60 (52.6%)

4.2. Factor Analysis

On the basis of the factor analysis (see Table 4), the teachers seemed to make their choices following three independent ways of thinking, which explain 56.7% of the variance:

1. A compact and purely didactic way of thinking, which refers to the teaching of the physics content and which is indicated in Table 4 by the "Teaching Approach" factor, which explains 24.6% of the variance. In accordance with this way of thinking, whichever method that the participants chose to teach physics, they consistently linked their preferences to all four of the variables of our theoretical model. Specifically, the teachers' choices were significantly linked to: (a) Meaningful student learning (SL) (in terms of the teaching method); (b) The significant personal gains or losses (AT) (in terms of the teaching method); (c) The important third-persons opinions (SN)

(in terms of the teaching method)); and (d) The perceived behavioral control (PBC) of the method. This behavior was expected because of the high Cronbach's alpha index that is related to the second set of questions (i.e., atm = 0.760). In addition, the results reveal a sophisticated way of thinking. The kindergarten teachers that follow this way of thinking combine their intentions to teach physics with all of the variables that are introduced by the theory of planned behavior [18–20], as well as with their assessments about the students' meaningful learning via the various teaching methods;

2. A partial-variable approach to the content, which is not linked to its selection, and that is based on the following way of the teachers' thinking: "I consistently choose content (physics and/or biology) for my teaching for which I have the skills to teach (PBC) (in terms of the content), and from which I assess whether my students will acquire meaningful knowledge" (SL) (in terms of the content). This way of thinking is indicated in Table 4 by the "Content Choice" factor, and it explains 18.9% of the variance. This approach of alternatively choosing either physics or biology content links the teachers' choices only to the internal relations of teaching and learning: the students' learning, and the teacher's ability to teach;
3. A personal approach to content, which is not linked to its selection, according to which any intention that the teacher has to choose physics of biology content entails personal gains or losses (AT) (in terms of the content), and important third-person opinions (SN) (in terms of the content). This way of thinking is indicated in Table 4 by the "Personal Gain and Recognition" factor, and it explains 13.2% of the variance, which indicates that the teachers approach the content as an independent social and professional variable (i.e., they expect profits and/or recognition when they choose content). On the other hand, the fact that there is no correlation between the last two ways of thinking (2 and 3) in approaching the content explains the relatively small Cronbach's alpha index that is related to the first set of questions (i.e., ac = 0.542), which indicates that there is no consistency between these two ways of thinking.

Table 4. Independent factors of teachers' views.

	Teaching Approach Factor	Content Choice Factor	Personal Gain and Recognition Factor
I intend to choose physics and/or biology content.	0.068	**0.712**	0.113
I achieve significant student learning (SL-Content).	0.077	**0.778**	0.084
I achieve significant personal gains or losses (AT-Content).	−0.056	0.401	**0.668**
Important third persons would approve it (SN-Content).	0.118	−0.131	**0.704**
I can control the teaching process (PBC-Content).	−0.063	**0.721**	−0.181
I intend to choose the discovery demonstration and/or inquiry-based teaching method to teach physics content.	**0.754**	−0.031	−0.074
I achieve significant student learning (SL-Teaching method).	**0.704**	0.249	−0.118
I achieve significant personal gains or losses (AT-Teaching method).	**0.711**	0.021	0.237
Important third persons would approve of it (SN-Teaching method).	**0.588**	0.079	−0.490
I can control the teaching method in my lessons (PBC-Teaching method).	**0.714**	−0.109	0.110

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization. [a] Rotation converged in 5 iterations. Total variance explained: 56.7%.

Overall, the factor analysis shows that the teachers who participated in the seminar chose the method for teaching the physics content by taking into account all of the variables of our hypothesis. In contrast, when the teachers are prompted to choose the content, they are only influenced by the internal relations of teaching and learning (i.e., the students' learning and the teacher's ability to teach).

4.3. Linear Regression Analysis

Tables 5 and 6 present the results of the linear regression that investigated our hypothesis of the linear correlation of the teachers' intentions to choose the content and/or the teaching method with the three variables of the theory of planned behavior (AT, SN, and PBC), and with the variable of the assessment of the students' meaningful learning (SL).

Table 5. Factors that affect content choice.

Reasons That Teachers Choose Physics and/or Biology Content				
Model		Standardized Coeff. Beta	t	Sig.
1	I achieve significant student learning (SL-Content).	0.457	4.228	0.000
	I achieve significant personal gains or losses (AT-Content).	0.238	2.223	0.028
	Important third persons would approve of it (SN-Content).	0.096	1.046	0.298
	I can control the teaching process (PBC-Content).	0.192	2.374	0.019

a. Dependent variable: E1; b. linear regression through the origin; c. adjusted R square = 0.929; sig. = 0.000.

Table 6. Factors that affect teaching-method choice for physics content.

Reasons for Choosing the Discovery Demonstration and/or Inquiry-Based Teaching Method, for Teaching Physics Content			
Model	Standardized Coeff. Beta	t	Sig.
I achieve significant student learning (SL-Teaching method).	0.242	2.785	0.006
I achieve significant personal gains or losses (AT-Teaching method).	0.172	1.779	0.078
Important third persons would approve of it (SN-Teaching method).	0.281	2.924	0.004
I can control the teaching method in my lessons (PBC-Teaching method).	0.292	3.338	0.001

a. Dependent variable: E6. b. Linear regression through the origin. c. Adjusted R square = 0.921; sig. = 0.000.

The results show that, when teachers express their intentions to choose the content (Table 5), their views are primarily dominated by their assessment that the students will acquire meaningful knowledge (SL-Content; $\beta = 0.457$, $p < 0.001$), and secondarily by the possible personal gains or losses (AT-Content; $\beta = 0.238$, $p < 0.05$). The assessment of the personal ability to control the teaching process (PBC-Content, $\beta = 0.192$, $p < 0.05$) seems to be less important, while the opinions of important third persons (SN-Content, $\beta = 0.096$, $p = 0.298$) do not seem to play an important role. In other words, the teachers' intentions towards the content selection is mainly explained by the variables that construct the "Content Choice Factor" (Table 4), but also secondarily by the teachers' assessments of their personal gains or losses (AT-Content).

On the other hand, when the teachers express their intentions to choose a teaching method for the physics content (Table 6), all of the variables that construct the "Teaching Approach" factor (Table 4) play significant roles, in the following order: the teacher's ability to implement and control the method (PBC-Teaching method; $\beta = 0.292$, $p < 0.05$); the opinions of important third persons (SN-Teaching method; $\beta = 0.281$, $p < 0.05$); the teachers' assessments in terms of the students' meaningful learning (SL-Teaching method; $\beta = 0.242$, $p < 0.05$); and the teachers' possible personal gains or losses (AT-Teaching method; $\beta = 0.172$, $p < 0.05$).

5. Discussion

The results of the study present a number of interesting points for discussion. They show that there was a smaller difference in the kindergarten teachers' intentions to choose the content (physics or biology), and a more important difference in their choice of teaching method (discovery demonstration or inquiry-based for the physics content). However, it seems that when it came to implementing the content and/or method, there was no difference in the teachers' ways of thinking.

On the one hand, whether the teachers chose content from physics or biology, or from both subjects equally, there was a common rationale behind all of the options, which is described by the "Content Choice" factor, which arose as a way of thinking from the factor analysis. The findings suggest that the kindergarten teachers chose the subject content that they had the skills to teach successfully (PBC), which, in light of effective teaching, is equivalent to the fact that the students are learning meaningful knowledge (SL). In this case, our hypothesis (that the "difficulty" and the "utility" of the subject matter of physics and/or biology may activate normative (SN) and personal (AT) factors that eventually influence the kindergarten teachers' intentions to choose the content [24–27]) does not show up. To the contrary, the two factors, SN and AT, seem to develop as independent social and professional variables, which means that the kindergarten teachers tend to focus on the expected recognition and personal profits (the "Personal Gain and Recognition" factor).

On the other hand, the common rationale behind the way that the kindergarten teachers chose the method—whether discovery demonstration (DD) or inquiry-based (I-B), or both methods equally—with which to teach physics is described by the "Teaching Approach" factor. This, in combination with the results of the linear regression, suggest a similar, albeit stronger reasoning than that for the choice of content. In other words, the teaching method was chosen on the bases of the teachers' consideration as to whether they had the skills to apply it successfully (PBC), and of their consideration as to whether their students would, thus, learn meaningful knowledge (SL). This reasoning is further enhanced by the teachers' assessments of whether important third persons would approve of their use of the particular method(s) (SN), and whether they would "enjoy themselves" teaching (AT). Therefore, our main hypothesis, that normative (SN) and personal (AT) factors would significantly elaborate the kindergarten teachers' intentions [18–20], seems to be brought about when they choose the teaching method.

Thus, overall, it would appear that the kindergarten teachers' intentions to use certain content and particular teaching methods seem to be based on a simple and straightforward rationale: "I choose to do what I have the skills to do successfully, and I do it in a way that my pupils will learn." Apart from this, their choice of teaching method(s) (but not of the content) is also associated with their assessment of the personal gains or losses, as well as of the opinions of important third persons.

These results also explain, to some extent, the quantitative differences in the descriptive analysis. One finding from the quantitative analysis is that the majority of kindergarten teachers chose the "both physics and biology equally" content option for their classroom teaching material. Similarly, when asked which subject's content they believed the students would gain the most meaningful knowledge from, the vast majority chose "both physics and biology equally". These choices were expected because, when teachers deal with the content of various subjects, they take into account their own didactic approach ("I can teach this content and my students will learn") instead of considering the contents' epistemological differences. This finding also explains the almost four-fold difference between their preferences for physics content over biology. In other words, the kindergarten teachers seem to have an internally consistent way of thinking about teaching the physics content, which is the "Teaching Approach" factor, as well as about the recent examples of the specific applications that they acquired in the seminar. It also offers an interpretation for the lower percentages of the "both physics and biology equally" option in terms of the teaching method choice for physics.

Overall, these results, which are due to the consistent didactic thinking of teachers, do not seem to be dominated by any particular preference. They also do not confirm our hypothesis that the teachers who chose biology would tend to choose the inquiry-based method to teach the physics content; this is most likely due to the fact that the low percentage of teachers who chose the biology content does not allow for a reliable analysis. Nevertheless, the study findings show that there were two distinct categories of kindergarten teachers. On the one hand, there were those whose teaching was based on the tradition of science education and who chose to apply either the discovery demonstration or inquiry-based teaching method. On the other hand, there were the teachers who opted to use the two teaching methods equally, irrespective of the content, and whose teaching was based in early childhood education.

6. Implications

On the basis of the above results, we consider that the organization of the training seminar should focus on the issues that could: (a) Upgrade the tradition of early childhood education, which kindergarten teachers are already familiar with, to a tradition that incorporates science education; and (b) Enrich the didactic approaches that kindergarten teachers use successfully with the epistemological aspects of the various science subject contents, which would reveal the role of the nature of science in teaching and learning.

More specifically, for each of the above cases:

1. The incorporation of the science education tradition, and, consequently, the use of a variety of teaching methods by kindergarten teachers, could be promoted by organizing training seminars that include activities that are either based on narrative texts from children's books, or on popular activities for kindergarten children that are readily found on the Internet. These should be adapted to the teaching methods and proposals of science education, as well as to research-based didactically transformed content [35,38]. It is also equally important for scientific descriptions to be rearranged into a narrative style. For example, from a "[. . .] and, [. . .] and, [. . .] and [. . .], therefore [. . .]" type of description, to a "[. . .] and [. . .], but [. . .], therefore [. . .]" type of description [45]. (For instance, from a description such as, "I have a plastic bottle of water, and I open a hole in it, and I notice that water is running out of the hole, therefore [. . .]", to a description such as, "Water is running out of the hole in a plastic bottle, but if I close the mouth of the bottle, it stops running, therefore [. . .]");
2. The epistemological aspects of physics and biology, as well as the images that the public has of them, can be distinct parts of the seminar discussions, and can be combined with the scientific practices that concern them. These scientific practices, on the basis of the particular teaching approaches, determine the ways in which the students learn [34,46,47]. The hypothetico-inductive method is promoted by the inductive inquiry-based teaching method, and it promotes learning through observation, categorization, and hypothesis construction. The scientific method of laboratory validation is promoted by the discovery demonstration teaching method, and it enhances learning through the empirical investigation of specific claims. The historical scientific method is also promoted by the inquiry-based teaching method, and it supports learning through the collection and conceptualization of time-dispersed data. In this case, it is important to convince kindergarten teachers that the different scientific methods are not graded as better or worse. With this logic, there are no better or worse teaching methods, just as there are no better or worse ways of learning. There are only different scientific and teaching methods, and different ways of learning, all of which are equally important and useful.

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Appendix A. The Questionnaire

Appendix A.1. First Set of Items—Content

I consider that it is possible to implement activities with content:

Only from Physics	Mostly from Physics	From Physics and Biology Equally	Mostly from Biology	Only from Biology

I consider that the knowledge that my pupils learn is more meaningful when they participate in activities with content:

Only from Physics	Mostly from Physics	From Physics and Biology Equally	Mostly from Biology	Only from Biology

I consider that, as a person/citizen and a teacher, I gain more when the content of the activities that I organize for my pupils is:

Only from Physics	Mostly from Physics	From Physics and Biology Equally	Mostly from Biology	Only from Biology

I consider that important third persons (pupils, pupils' parents, supervisors, etc.) would approve when the content of the activities that I organize for my pupils is:

Only from Physics	Mostly from Physics	From Physics and Biology Equally	Mostly from Biology	Only from Biology

I consider that I am more capable of organizing and implementing teaching activities when the content of the activities is:

Only from Physics	Mostly from Physics	From Physics and Biology Equally	Mostly from Biology	Only from Biology

Appendix A.2. Second Set of Items—Teaching Methods When the Content Is Physics

The teaching method that I consider most adoptable for activities with content from physics is:

Only Discovery Demonstration	Mostly Discovery Demonstration	Equally Discovery Demonstration and Inquiry-based	Mostly Inquiry-based	Only Inquiry-based

I consider that the knowledge that my pupils learn is more meaningful when the teaching method of the activities with the physics content is:

Only Discovery Demonstration	Mostly Discovery Demonstration	Equally Discovery Demonstration and Inquiry-based	Mostly Inquiry-based	Only Inquiry-based

I consider that, as a person/citizen and a teacher, I gain more when the teaching method of the activities with the physics content is:

Only Discovery Demonstration	Mostly Discovery Demonstration	Equally Discovery Demonstration and Inquiry-based	Mostly Inquiry-based	Only Inquiry-based

I consider that important third persons (pupils, pupils' parents, supervisors, etc.) would approve when the teaching method of the activities with the physics content is:

Only Discovery Demonstration	Mostly Discovery Demonstration	Equally Discovery Demonstration and Inquiry-based	Mostly Inquiry-based	Only Inquiry-based

I consider that I am more capable of organizing and implementing teaching activities when the teaching method of the activities with the physics content is:

Only Discovery Demonstration	Mostly Discovery Demonstration	Equally Discovery Demonstration and Inquiry-based	Mostly Inquiry-based	Only Inquiry-based

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Article

Interpersonal Meaning: Verbal Text–Image Relations in Multimodal Science Texts for Young Children

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Abstract: Verbal text and images constitute the principal semiotic modes interacting to produce interpersonal meanings in multimodal science texts for young children. These meanings relate to pedagogical perceptions about children's learning. This study examined verbal text–image relations regarding the interpersonal meaning dimensions of address (the way the reader is addressed), social distance (the kind of the relationship between the reader and represented participants), and involvement (the extent to which the reader is engaged with what is represented) in multimodal text excerpts from science-related books for preschool children. The sample consisted of 300 randomly selected units of analysis. For each unit, the verbal and the visual content was analyzed along each dimension, and the relevant verbal text–image relation was determined. Results indicated that regarding address and involvement, relations of convergence appeared significantly more frequently than relations of complementarity and divergence. Concerning social distance, relations of complementarity and divergence were observed more frequently than relations of convergence. Results are discussed in the context of the Systemic Functional Grammar and the Grammar of Visual Design, in the light of the socio-cognitive perspective on science teaching and learning. Implications for the selection, design, and use of multimodal science texts for young children are also discussed.

Keywords: address; interpersonal meaning; involvement; multimodal texts; science; social distance; socio-cognitive perspective; verbal text–image relations; young children

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1. Introduction

'Multimodality' has been widely used to denote the contribution of different semiotic modes in the construction of meaning [1]. Teaching and learning in science are considered as multimodal processes, where a multitude of semiotic modes (e.g., language, visual representations, gestures, and body language) contribute to the presentation and communication of scientific meanings, while inter-semiotic interaction produces new meanings during instruction [2–10]. This multiplicity and complexity of meanings produced by the interplay of various modes suggests that in the context of a 'pedagogy of Multiliteracies' [11] students, from an early age [12,13], need to be able to analyze, interpret, critically understand, and use different representational modes of meaning-making, as well as the ways these modes interact [11,14–16].

Teaching materials play a key role in science learning [17,18]. More particularly, during early childhood, children's interaction with science-related texts is an integral part of their first learning experiences. Among different kinds of such materials, informational books are widely used by preschool teachers as instructional aides to introduce science concepts and phenomena in the classroom [19,20]. Science teaching material for young children is vastly multimodal, i.e., it involves the synergy of different modes of representation [21,22], with verbal text and image being prevalent [23].

Analyses of multimodal teaching materials often draw on two fundamental theoretical schemes: The Systemic Functional Grammar and the Grammar of Visual Design. The Systemic Functional Grammar [24] is a grammatical model that belongs in a broad social semiotic approach to language (i.e., Systemic Functional Linguistics). According to this model, language is a system, namely a set of available choices for making meaning, and language functions (or "metafunctions") relate to different levels of meanings [24]. The Grammar of Visual Design [25] is a social semiotic approach to visual communication and describes the visual resources available for constructing meaning through images. It was based on the semiotic principles of Systemic Functional Grammar and supports that the metafunctions of language apply also to images [25].

Therefore, according to the Systemic Functional Grammar [24] and the Grammar of Visual Design [25] in every text the verbal and the visual mode can produce meaning in three different levels: the representational (actions, participants involved in them, and overall context), the compositional (composition of verbal and visual elements on the page) and interpersonal (relations between writer and reader, and reader–represented knowledge).

The interpersonal meaning is particularly significant pedagogically, since it relates to a crucial interaction taking place in educational environments, namely the interaction between the learner and the teaching material [26]. More specifically, the selections made in the construction of teaching material regarding interpersonal meaning shape the role assigned to the reader and how s/he is positioned vis-à-vis the presented knowledge [3,27–29]. The interpersonal meaning promoted by an educational material delineates the terms of the child's interaction with it and her/his knowledge construction, while it reflects the pedagogical positions that—deliberately or not—underly its design. Therefore, the semiotic selections regarding the interpersonal meaning disclose specific views about the child's role in the learning process as well as the nature of knowledge and its construction, consequently affecting the quality and effectiveness of the learning experience resulting from the use of the material [30–35].

Furthermore, interpersonal meaning becomes even more important in the light of the socio-cognitive perspective on science learning, according to which science teaching materials are mediating tools and the young readers' interaction with them determines the learning process [36,37]. The interpersonal meaning is particularly significant for preschool education, during which children acquire their first experiences with science topics, which are largely based on interactions with multimodal materials [20].

The aim of the present study is to investigate verbal text–image relations regarding the interpersonal meaning in excerpts from multimodal science-related books for preschool children (2.5–6 years old). The study adopts a socio-cognitive perspective [36,37] on teaching and learning science. More particularly, it draws upon key assumptions of the socio-cognitive model for designing science teaching material. In the following sections these assumptions and their association with the dimensions of interpersonal meaning will be presented, followed by a presentation of the interpersonal meaning dimensions and the relations between verbal text and image in regards to interpersonal meaning. Then, the rationale, research question and hypotheses of the study are exposed.

2. Interpersonal Meaning and Key Socio-Cognitive Assumptions

The interpersonal meaning is a particularly significant aspect of science teaching and learning in the socio-cognitive framework, according to which knowledge is constructed and transformed by the child in the context of social and physical interaction with others (e.g., peers, teachers) and culturally mediated tools and artifacts [37–40]. Science learning occurs through children's interactions with other members of the school community and with teaching material [17,36,41–43]. These interactions determine children's construction of scientific knowledge [44]. In the context of the socio-cognitive perspective, then, the terms of communication, the kinds and forms of the aforementioned interactions become of critical importance for the learning process [45]. Moreover, particular emphasis is given to the role of teaching materials as mediating tools and to the way they present knowledge.

Within this framework, special attention is paid to the function of teaching materials in shaping the role of the learner and her/his relation with the represented knowledge. Therefore, an analysis of teaching materials' interpersonal characteristics can shed light on the pedagogical assumptions underlying their design [30,34,40,46].

According to the socio-cognitive framework [36,37], children do not acquire knowledge passively. Instead, they are considered as active agents who construct knowledge in the context of social interactions and teaching mediation, based on their previous science-related experiences and conceptions [36,37,47–49]. Under the socio-cognitive lens, knowledge is not seen as objective or independent of the learner, but closely related to the child's life, while knowledge construction, i.e., learning, presupposes her/his action, participation, and active engagement [39,41,48,50].

Therefore, the design of science teaching material which aligns with the socio-cognitive perspective (i) addresses young readers by assigning them an active role in their own learning, (ii) promotes the development of an intimate social relationship between the reader and the represented knowledge, and (iii) engages the reader with what is presented [32,33,51–53]. In the context of the present study, the degree to which these characteristics are reflected in the verbal and visual semiotic selections of a text refers to *address*, *social distance*, and *involvement* respectively, namely three fundamental dimensions of the interpersonal meaning [24,25]. These dimensions are analyzed in the following paragraphs.

3. Interpersonal Meaning Dimensions in Verbal Text and Image

As already mentioned, interpersonal meaning is verbally and visually constructed and promoted in multimodal science teaching material by means of three dimensions, namely (a) *address*, (b) *social distance*, and (c) *involvement* (Figure 1). Power relations between reader and represented participants constituting the fourth dimension of interpersonal meaning and realized verbally by the use of evaluative language and visually by the vertical angle of the image [25], was not examined in the present study. This selection derives from the nature of the current study and the particular characteristics of the material. Specifically, informational science books for preschool children typically involve a very short verbal text consisting of simple clauses and evaluative words or vertical angles other than eye-level shots are mostly absent. More particularly,

- *Address* refers to the way a text addresses the reader. Address is verbally realized by the type of clause used (i.e., imperative, for example "Show the planets' motion around the sun", interrogative, e.g., "Have you ever seen a lightning?" or declarative, e.g., "We have five senses: We can see, hear, smell, taste and touch") and the person of the verb in a clause [24]. Visually, address is articulated by means of the presence or absence of the represented participants' gaze towards the reader [25,54]. The term "represented participants" refers to the verbally and visually represented living entities, people, or animals, participating in the actions presented in the verbal text and images [25].
- *Social distance* reflects the kind of social relationship between the reader and the represented participants promoted by a text. Verbally, social distance is expressed through the voice of the verb (active or passive) and the type of relationship between clauses (parataxis/absence of subordinate clauses or hypotaxis) [24]. In the Greek language there are four choices regarding the voice of the verb: active, i.e., the subject of the verb performs an action (e.g., "The sun heats the earth"), passive, i.e., the subject of the verb receives an action (e.g., "The earth is heated by the sun"), middle, i.e., the subject of the verb both performs and receives an action, or neutral, i.e., the subject of the verb neither performs nor receives an action, but is in a state (e.g., "In winter, brown bears hibernate"). Regarding the type of relationship between clauses, the choices are parataxis (e.g., "In autumn the leaves of some plants change color and fall"), absence of subordinate clauses (e.g., "During hibernation bears do not need to eat"), or hypotaxis (e.g., "When water droplets get too heavy in the cloud, they fall to earth as rain"). In images, social distance is realized by the size of frame, referring to

whether the participant's body is depicted in full, or partly. In particular, size of frame relates to three visual choice alternatives: close, medium, or long shot [25].

- *Involvement* is associated with the degree to which the reader is invited to engage with what is represented. Involvement is verbally articulated through the person of the possessive pronouns (first, second or third) [24] and visually expressed by means of the horizontal angle of the image (frontal or oblique) [25].

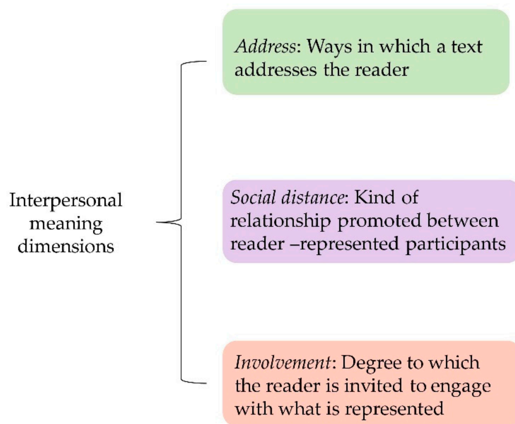

Figure 1. Dimensions of interpersonal meaning [24,25].

4. Relation Between Verbal Text and Image Regarding Interpersonal Meaning

The overall interpersonal meaning conveyed by a multimodal text is not formed by the distinct contribution of verbal text and image, but from their interrelation [55–57]. For each dimension of interpersonal meaning (address, social distance, and involvement), the verbal and the visual mode in a text can be characterized as [58]

1. *Convergent*, when they produce similar meanings (e.g., when both verbal text and image denote low address, i.e., simply present information to the reader instead of calling her/him to undertake some action);
2. *Complementary*, if one of the semiotic modes contributes additional meanings to those promoted by the other (for instance, verbal text denoting familiarity with the reader, i.e., signifying small social distance combined with an image signifying moderate social distance between the reader and the represented entities); or
3. *Divergent*, when the two modes promote contradictory meanings (e.g., when the verbal text promotes strong reader involvement with what is represented, while the image discourages reader involvement).

Exploring the relations between verbal text and image in science-related multimodal texts for children is important for science education, since it has been suggested that young readers have a difficulty in appropriately associating verbally and visually conveyed information during their early encounters with such texts, and this affects their understanding of the presented knowledge [59–65]. Previous studies [66–69] have indicated the significance of prompting similar meanings through verbal text and image in multimodal texts addressing children, since this similarity of meanings facilitates understanding. Meaning convergence between the two modes facilitates the cognitive process of creating associations between verbal and visual representations, which is a requirement for comprehending multimodal texts [70]. The convergence relation is considered to be the optimal for enhancing children's understanding of various types of text, while more complex relations between the verbal and the visual mode, like complementarity, may cause difficulties to young readers [67,69]. In addition, divergence relations between word and image tend to pose further challenges to children and lead to confusion and misinterpretations of the represented knowledge [71].

It is suggested that the interpersonal meanings promoted by verbal text and image in multimodal science teaching materials should align with the socio-cognitive principles on science learning. In particular, science teaching materials are expected to assign an active role to the child in the process of knowledge construction, to promote an intimate relation between the child and the represented knowledge, and to encourage the child to engage with it [32,33,51–53]. Therefore, science teaching materials designed according to the socio-cognitive perspective on learning, promote both verbally and visually (see Figure 2):

- High address, encouraging the reader to perform some action regarding the represented knowledge, therefore acknowledging the readers' active role in their own learning;
- Small social distance between the reader and what is represented, thus implying intimacy and familiarity;
- Strong involvement of young readers, by presenting knowledge as belonging in their personal world and experiences and inviting them to engage with it.

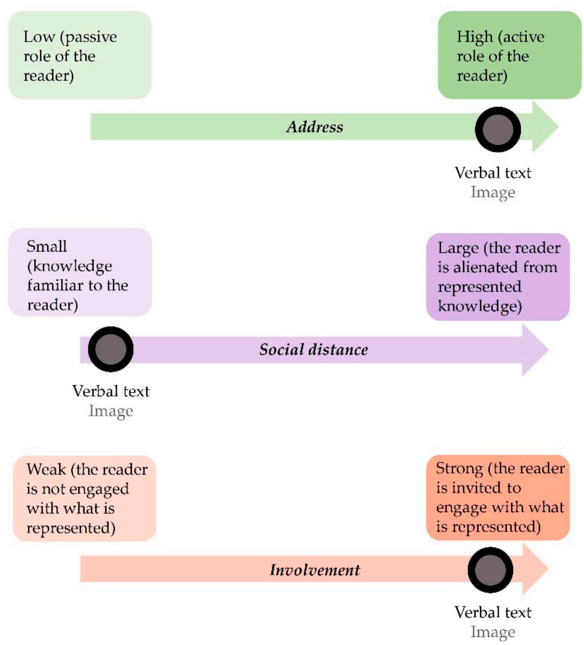

Figure 2. Verbal and visual semiotic selections and their correspondence to key socio-cognitive assumptions.

5. The Present Study

As already mentioned, the interpersonal meaning promoted by teaching materials is significant for science education, since it reflects the pedagogical views about the learner's role in the construction of knowledge, thus affecting the quality and effectiveness of the learning experience supported by the use of these materials. This meaning is particularly important for the preschool years when children develop their first systematic science learning experiences, which extensively rely on their interaction with multimodal texts. This kind of materials largely involves informational books covering topics from biology and physics [20,72]. Since meaning in these multimodal books is not constructed through the distinct contribution of each mode, but through their synergy and interaction [11,22,73–76], understanding how these two modes interrelate is a precondition for their comprehension [77,78]. Several studies [79–85] have focused on the interpersonal meaning in children's picture books. It is showed that verbal text and images promote low address, serving the presentation of information to the young readers in such books [79–81]. Furthermore, some studies indicated that images in picture books promote an intimate relationship between readers and represented participants [82,84] and invite readers to engage with what is presented [82], while other studies found that a remote relationship is promoted [79,80,85] and the reader is not engaged [79] visually. However, research on the dimensions of interpersonal meaning promoted by verbal text and/or images in science materials [27,29,33,51,52,86] and more particularly those addressing young children [53] is limited.

Exploring the relation between the verbal and the visual mode in science teaching materials is important, especially in the case of those addressed to young children. It has been suggested that children find it difficult to appropriately coordinate verbal text and image in such multimodal texts, which affects their comprehension of the presented knowledge [62,64,68,87]. In fact, it has been indicated that different kinds of relation between verbal text and image affect children's comprehension in varying degrees [67,69]. However, research on verbal text–image relations in multimodal science texts for children has mainly explored the representational or the compositional meaning [88–93]. Furthermore, previous research on the interpersonal meaning in multimodal science texts has examined the distinct contribution of the verbal and the visual mode in meaning construction instead of their interrelation [27,29,33,51,52,86]. Studies on verbal text–image relations in terms of the interpersonal meaning in science teaching material for preschool children are practically absent from the international literature, despite the pedagogical impact of this meaning on young children's science learning.

In an attempt to fill this gap, the present study aims at addressing the following research question: What are the relations between verbal text and image promoted by multimodal texts about science in related books for preschool children regarding the interpersonal meaning dimensions of address, social distance, and involvement?

Adopting the socio-cognitive perspective on science learning [36,37,39,41,47,48], it was expected that the material under study, both verbally and visually, would ascribe children with an active role as readers/learners, by instilling an intimate relation between them and the presented knowledge, and by encouraging their engagement with what is represented. More particularly, based on our hypotheses outlined below, it was expected that the verbal and the visual mode in excerpts from multimodal science books for young children would promote:

Hypothesis 1 (H1). *Convergent interpersonal meanings instead of complementary or divergent ones.*

Hypothesis 2 (H2). *High address.*

Hypothesis 3 (H3). *Small social distance between the child and what is presented.*

Hypothesis 4 (H4). *Strong reader involvement with the presented knowledge.*

It is noted that in the current study the verbal and the visual choices related to interpersonal meaning are analyzed and discussed according to the Systemic Functional Grammar [24] and the Grammar of Visual Design [25] and examined through the lens of the socio-cognitive perspective. Therefore, the current study neither examines the book creators' intention regarding the semiotic choices analyzed, nor considers the semiotic choices as a result of the intention of the books' creators.

6. Materials and Methods

6.1. Sample

Since there are no valid and official records of the constantly expanding publishing production, the creation of a complete list of all population units from which the sample could be randomly selected was not feasible. For this reason, the following sampling procedure was followed. Firstly, in order to determine the appropriate material for the aims of the study, books related to science for preschool children available in the Greek market and written or translated in Greek were systematically searched on the Internet using book-selling websites. Search results were limited to those meeting the following criteria:

- Informational books, namely books aiming to familiarize young children with concepts, phenomena, processes etc. [94]. Science-related books addressing preschool children but belonging in other genres (such as activity books, fictional books) were excluded for consistency, because of the different purposes, content type, and writing style in these book categories.
- Books published within the last decade from the sampling date (2018). This criterion was applied in order for the sample to include recent books, therefore available for purchasing, but also revealing the current trends and probably echoing contemporary pedagogical perceptions on learning, and more particularly the socio-cognitive perspective.

This process has allowed the construction of a list of Greek publishing companies which publish such books. A written request was sent to all these publishers to supply a copy of their books that met the abovementioned criteria for our research purposes. Seven Greek publishing companies responded to this request, offering a total of 55 books, from which 30 fully complied with the criteria. According to the descriptions on their publishers' catalogues, these specific books are aimed at preschool children, aged 2.5–6 years [95,96]. These 30 books were divided into units of analysis. Each unit of analysis consisted of an image and the verbal text accompanying it. Since the estimation of address for the visual mode is based on the direction of the participant's gaze (towards the reader or elsewhere) [25], units that did not include images of living entities as participants (i.e., people, animals, or anthropomorphic entities illustrated with eyes) were excluded from the sampling process. Through this process, the 30 books were divided into a total of 670 units. A list comprising all these units was created. A sequential number was assigned to each unit in the list. Using simple random sampling, a total of 300 units of analysis were selected, which formed the sample of this study. In specific, using the random number generator of SPSS statistics program, 300 random numbers were selected from the 670 numbers of the list. The units of analysis with sequential numbers corresponding to these randomly selected numbers were included in the sample. The sample size of 300 units of analysis was estimated as adequate considering the number of interpersonal meaning dimensions examined in the study, the number of levels of each dimension and the number of verbal text–image categories.

6.2. The Framework of Analysis

For the purposes of the present study a framework of analysis was constructed, including the realization means of each dimension of interpersonal meaning, the different levels of each dimension, and the specific choices indicating each level of dimension for the verbal and the visual mode. This framework was based on the Systemic Functional Grammar [24] and the Grammar of Visual Design [25] regarding the verbal text and images, respectively. Furthermore, regarding verbal text–image relations the framework was based on the three basic categories of relations: convergence, complementarity, and divergence [58]. For each dimension of interpersonal meaning (i.e., address, social distance, and involvement) and for each of the two semiotic modes (SM), the framework of analysis included: the realization means, the levels of each dimension, and the rules for classifying the content into each level. Furthermore, it included the categories of verbal text–image relation and the classification rules for each category. For the construction of the analysis framework, the criteria of exhaustiveness and mutual exclusiveness were taken into account, so that the content of each unit of analysis could be classified into one of the levels of the dimension and could not fall into more than one levels, respectively. The framework of analysis is presented in Figure 3 and is described below in detail.

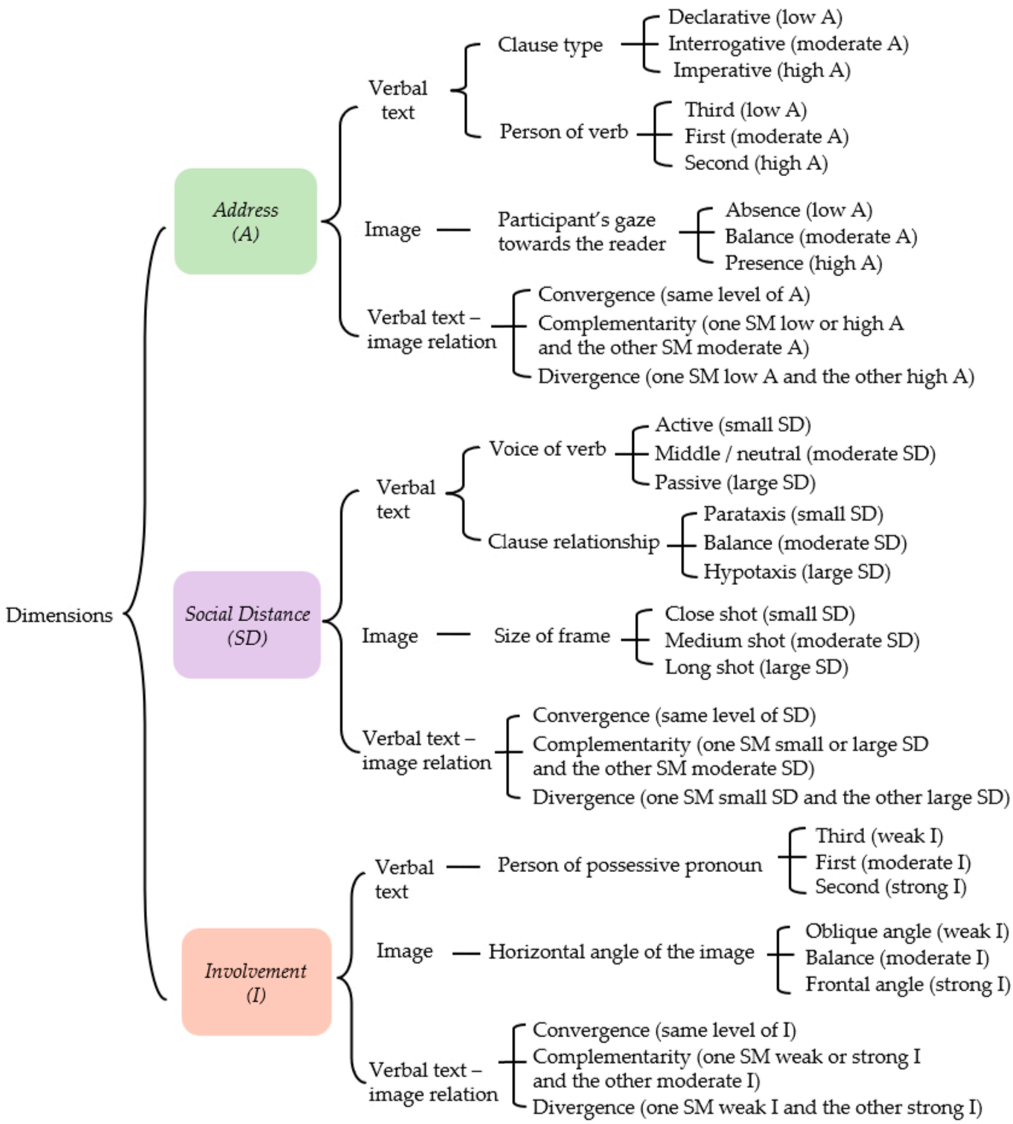

Figure 3. The framework of analysis.

6.3. Analysis Procedure

For each unit of analysis, the verbal and the visual content was classified with regard to each dimension of interpersonal meaning (i.e., address, social distance, and involvement) at one of the levels of each dimension according to the classification rules and then the category of verbal text–image relation was defined. Consistency between two coders, who coded independently 30 units of the total sample, was assessed using Cohen's Kappa which indicated high ($\kappa > 0.80$) interrater reliability [97,98] for the dimension of address, social distance, and involvement ($\kappa = 0.88$, $\kappa = 0.84$ and $\kappa = 0.89$, respectively). Inconsistencies between the two coders were resolved by a third coder as proposed by several researchers [97–99].

6.3.1. Classification of Verbal and Visual Content in Relation to Address

Regarding the verbal text, address was assessed based on the combination of clause type and the person of the verb. For example, address was classified as "low" when there was a combination of a declarative clause and third person (e.g., "Giraffes live in the savannas of Africa" [100] p. 8), as "moderate" when an interrogative clause and a verb in the first person were combined (e.g., "Do I have the same shape as my shadow?"), and as "high" when an imperative clause and second person were combined (e.g., "Avoid looking directly at the sun!" [101] p. 11).

Visually, address was determined by assessing the depicted participants' gaze. The visual content was classified as "low address" when the participants did not gaze towards the reader and as "high address" when the participants gazed towards the reader. The content was categorized as "moderate address" when there was an equal number of participants gazing and not gazing towards the reader, signifying balance between high and low address.

Classification rules for the verbal (clause type, person of verb and their specific combinations) and visual (participants' gaze) realization means for address are summarized in Table 1.

Table 1. Levels of address, realization means, and classification rules.

Address	Verbal Text			Image
	Clause Type	**Person of Verb**	**Combination**	**Participants' Gaze**
Low (L)	Declarative	Third	L+L or L+M	Participant(s) not gazing towards the reader
Moderate (M)	Interrogative	First	M+M or H+L	Equal number of participants gazing and not gazing towards the reader
High (H)	Imperative	Second	H+H or H+M	Participant(s) gazing towards the reader

For reasons of exhaustiveness, when a unit of analysis involved different types of clauses, address was classified as "low" when there was an equal number of declarative and interrogative clauses, as "moderate" when there was an equal number of declarative and imperative clauses, and as "high" when there was equal number of imperative and interrogative clauses. Similarly, concerning the person of the verb, the content was classified as "low address" when there was equal number of verbs in the first and the third person, as "moderate" when there was an equal number of verbs in the third and the second person, and as "high" when there was an equal number of verbs in the first and the second person.

6.3.2. Classification of Verbal and Visual Content in Relation to Social Distance

Regarding the verbal text, social distance was estimated based on the combination of the voice of the verb and the type of relationship between clauses. For example, social distance was categorized as "small" when active voice of the verbs and parataxis were combined (e.g., "Squirrels climb tree trunks and jump from tree to tree"), as "moderate" when there was a combination of middle/neutral voice of the verbs and balance between parataxis and hypotaxis (e.g., "When brown bears hibernate, they stay in their dens and rest"), and as "large" when there was a combination of passive voice and hypotaxis (e.g., "If the earth was not heated by the sun, it would be frozen").

Visually, social distance was determined by the size of frame and was estimated as "small" when participants were depicted in a close shot (e.g., when the head and the shoulders, or only the head of a participant was depicted). The visual content was categorized as "moderate social distance" when participants were depicted in a medium shot (i.e., when a participant's body was 'cut' to the chest, waist, or knees, or the full body was depicted occupying more than 50% of the image space), and as "large" when participants were depicted in a long shot (the full body was depicted, occupying less than 50% of the image space).

Table 2 presents the classification rules of the verbal (voice of verb, relationship between clauses and their combinations) and the visual (size of frame) content.

Table 2. Levels of social distance, realization means, and classification rules.

Social Distance	Verbal Text			Image
	Voice of Verb	Clause Relationship	Combination	Size of Frame
Small (S)	Active	Parataxis or absence of dependent clauses	S+S or S+M	Close shot
Moderate (M)	Middle/neutral	Balance between parataxis or absence of dependent clauses and hypotaxis	M+M or S+L	Medium shot
Large (L)	Passive	Hypotaxis	L+L or L+M	Long shot

For reasons of exhaustiveness, when a unit of analysis included more than one verbs of different voices, social distance was classified as "small" when there was an equal number of verbs in active and middle/neutral voice, as "moderate" when there was an equal number of verbs in active and passive voice, and as "large" when there was an equal number of verbs in passive and middle/neutral voice.

6.3.3. Classification of Verbal and Visual Content in Relation to Involvement

Regarding verbal text, involvement was estimated by the person of the possessive pronouns used. Thus, the verbal content was classified as "weak involvement" when the pronoun used was in the third person (e.g., "her"/" his", as in the following sentence: "A butterfly lays her eggs on a plant leaf" ([102] p. 31). The absence of possessive pronouns in the verbal text also indicated "weak involvement". The content was classified as "moderate involvement" when the pronoun used was in the first person (e.g., "my/ our", as in the sentence: "The sun is at the center of our solar system" ([103] pp. 18–19) and as "strong involvement" for the use of a second-person possessive pronoun (e.g., "your", as in the following sentence: "Your teeth cut the food into small pieces" [104] p. 20).

Visually, involvement was determined by the horizontal angle of the image. The content was categorized as "weak involvement" when the participants were illustrated in an oblique angle and as "strong involvement" when the participants were illustrated in a frontal angle. The visual content was categorized as "moderate involvement" when there was an equal number of participants in oblique and frontal angles, signifying balance between weak and strong involvement (Table 3).

Table 3. Levels of involvement, realization means, and classification rules.

Involvement	Verbal Text	Image
	Person of a Possessive Pronoun	Horizontal Angle of the Image
Weak (W)	Third person	Participant(s) depicted in an oblique angle
Moderate (M)	First person	Equal number of participants in an oblique and frontal angle
Strong (S)	Second person	Participant(s) depicted in a frontal angle

For reasons of exhaustiveness, when the verbal content in a unit of analysis involved more than one possessive pronouns, involvement was classified as "weak" when there was an equal number of possessive pronouns in the first and the third person, as "moderate" when there was an equal number of pronouns in the third and the second person, and as "strong" when there was an equal number of possessive pronouns in the first and the second person.

6.3.4. Classification of Verbal Text–Image Relation for Each Dimension of Interpersonal Meaning

The verbal text–image relation in a unit of analysis was categorized as "convergence" when the two semiotic modes had been classified at the same level of the dimension. Alternatively, when one of the modes had been classified at one of the extreme levels and the other had been classified at the moderate level (e.g., a unit of analysis involving a verbal text of high address and a visual image of moderate address) their relation was characterized as "complementarity". Last, relations of "divergence" between the two semiotic modes appeared when the verbal and the visual part of a unit of analysis had been classified at the two opposite extreme levels (e.g., a unit of analysis with the verbal text indicating small social distance and the image evoking large social distance).

For example, the verbal mode of the multimodal text in Figure 4 consists of the following clauses: "Wings help the airplane fly", "Does the airplane move its wings?" [105]. The verbal text in this unit of analysis indicates "low address" since it combines a declarative (first) and an interrogative (second) clause, while the verbs used are in the third person. "Low address" is also promoted visually, since the depicted participant (child) does not gaze towards the reader. Therefore, verbal text and image are characterized by convergence regarding the dimension of address. Furthermore, the verbal text promotes small social distance, since the verbs used are in the active voice ("fly", "move") and there are no subordinate clauses. The image indicates moderate social distance because the child is depicted in a medium shot (the child's body is "cut" to the chest). Therefore, in this unit of analysis verbal text and image are characterized by complementarity as far as social distance is concerned. Last, the verbal text promotes weak involvement since the third-person possessive pronoun ("its") is used, while the image denotes strong involvement as the child is depicted in a frontal angle. Therefore, the two semiotic modes in this unit are characterized by the relation of divergence regarding involvement [105].

Figure 4. Example of a multimodal text indicating different verbal text–image relations regarding each dimension of interpersonal meaning. Reproduced with permission from R. Spiro, *Geia sou poulaki!* [105]; published by Psichogios Publications: Athens, Greece, 2018.

7. Results

Table 4 presents the observed frequencies of verbal text–image relations for each level of address, social distance, and involvement in the analyzed units. Therefore, regarding address, the majority of units of analysis are characterized by a relation of convergence, with the two semiotic modes mostly indicating low address towards the reader. Furthermore, concerning social distance, relations of complementarity, and divergence were the most common in the sample, with verbal text tending to promote small social distance between the reader and represented participants and images indicating moderate or large social distance. Moreover, as far as involvement is concerned, the analyzed multimodal texts tend to be characterized by convergence, with verbal text and image mostly indicating weak reader involvement. These dominant tendencies are highlighted in bold in Table 4.

Table 4. Interpersonal meaning dimension levels for verbal text and image per category of relationship.

Verbal Text –Image Relation	Address			Social Distance			Involvement		
	Verbal Text	Image	*N*	Verbal Text	Image	*N*	Verbal Text	Image	*N*
Convergence	**Low**	**Low**	**120**	Small	Small	18	**Weak**	**Weak**	**98**
	Moderate	Moderate	13	Moderate	Moderate	19	Moderate	Moderate	17
	High	High	18	Large	Large	13	Strong	Strong	35
	Total		**151**	Total		50	Total		**150**
Complementarity	Low	Moderate	23	**Small**	**Moderate**	**79**	Weak	Moderate	25
	Moderate	Low	21	Moderate	Small	16	Moderate	Weak	27
	High	Moderate	4	Large	Moderate	15	Strong	Moderate	8
	Moderate	High	11	Moderate	Large	27	Moderate	Strong	5
	Total		59	Total		**137**	Total		65
Divergence	Low	High	70	**Small**	**Large**	**100**	Weak	Strong	64
	High	Low	20	Large	Small	13	Strong	Weak	21
	Total		90	Total		**113**	Total		85

In order to answer the research question, statistical analysis using the chi-square goodness of fit test for each dimension of interpersonal meaning was performed. Results indicated that the three categories of verbal text–image relation were not equally distributed concerning the dimension of address (χ^2 (2, N = 300) = 43.82, $p < 0.001$), social distance (χ^2 (2, N = 300) = 40.38, $p < 0.001$) and involvement (χ^2 (2, N = 300) = 39.50, $p < 0.001$).

Further chi-square tests (with an alpha level adjusted to 0.017) were conducted for each dimension of interpersonal meaning to determine statistically significant differences between pairs of categories (i.e., between convergence and complementarity, between complementarity and divergence, and between convergence and divergence). Regarding address, results indicated that relations of convergence were observed more frequently than expected compared to complementarity (χ^2 (1, N = 210) = 40.31, $p < 0.001$) and divergence (χ^2 (1, N = 241) = 15.44, $p < 0.001$). Moreover, divergence was observed more frequently than expected compared to complementarity (χ^2 (1, N = 149) = 6.45, $p = 0.011$). These results support our first hypothesis (H1) that science-related multimodal texts would mostly involve convergent verbal and visual meanings regarding address. However, this convergence relation is not in the expected direction since verbal text and image tend to indicate low address (Table 4) and not high address as expected (H2). For example, as already indicated in Figure 4 above, verbal text and image are characterized by convergence [105], with the two semiotic modes indicating low address toward the reader.

Concerning social distance, results demonstrated that convergence appeared less frequently than expected compared to complementarity (χ^2 (1, N = 187) = 40.48, $p < 0.001$) and divergence (χ^2 (1, N = 163) = 24.35, $p < 0.001$). No statistically significant differences were observed between frequencies of complementarity and divergence relations. The results do not support the hypothesis that science multimodal texts would be mostly characterized by relations of convergence regarding social distance (H1). Specifically, the hypothesis that verbal text and image would tend to promote small social distance (H3) was not confirmed. Moreover, in both prevalent relation categories, the verbal text tended to induce small social distance, while images tended to indicate moderate social distance in complementarity relations and large social distance in divergence relations (see Table 4). Figure 5 presents an example of a multimodal text characterized by complementarity, with the verbal text "Touch the little elephant's ear and hear him!" [106] inducing small social distance (use of active voice and parataxis) and the image promoting moderate social distance (the elephant's full body is depicted occupying more than 50% of the image space).

Figure 5. Example of a multimodal text indicating complementarity regarding social distance and convergence regarding involvement. Reproduced with permission from Hegarty, *Ta pio glika zoakia* [106]; published by Susaeta Hellas Publications: Athens, Greece, 2016.

With regard to involvement, the results indicated that relations of convergence were observed more frequently than expected compared to complementarity (χ^2 (1, N = 215) = 33.61, $p < 0.001$) and divergence (χ^2 (1, N = 235) = 17.98, $p < 0.001$). Therefore, these results support the hypothesis (H1) that science multimodal texts would mostly involve relations of convergence regarding involvement. However, this convergence is not in the expected direction, since verbal text and image tend to indicate weak involvement (Table 4) instead of strong reader involvement as expected (H4). For example, in Figure 5, verbal text and image are characterized by convergence, with the two semiotic modes indicating weak involvement of the reader (absence of possessive pronouns in the verbal text "Touch little elephant's ear and hear him!" [106] and oblique angle in the image).

8. Discussion

This study explored the relations between the verbal and the visual mode at the level of interpersonal meaning (i.e., in terms of address, social distance, and involvement) in multimodal science texts for preschool children. The results presented in the previous section indicate that the two semiotic modes tend to promote convergent meanings regarding address, primarily serving the purpose of simply presenting knowledge to readers and assigning them a passive role of information receivers (Figure 6). Similar findings have also been reported by previous studies that analyzed the verbal [33,107] and both the verbal and the visual [29] mode in science texts for primary and secondary students.

Verbal text and image also converge in respect to the dimension of involvement, by mostly discouraging the child to become engaged with what is represented (Figure 6). These findings do not align with the socio-cognitive assumptions according to which children are agents in meaning construction, which presupposes their action, participation, and engagement in the learning process [36,37,41,48]. Therefore, as far as address and involvement are concerned, despite producing convergent meanings (which confirms H1), the two semiotic modes tend to refute the socio-cognitive perspective on which H2 and H4 have been based.

Moreover, as the results presented in the previous section indicate, verbal text and image promote either complementary or divergent interpersonal meanings regarding social distance. More particularly, while the verbal mode seems to consistently promote a relationship of familiarity and intimacy between the child and the represented knowledge, the visual mode does not follow this trend, by conveying either a neutral relationship (in the case of complementary meanings), a finding also reported previously regarding images in books for primary students [52], or a relationship of alienation (in the case of divergent meanings) between the child and represented knowledge (Figure 6).

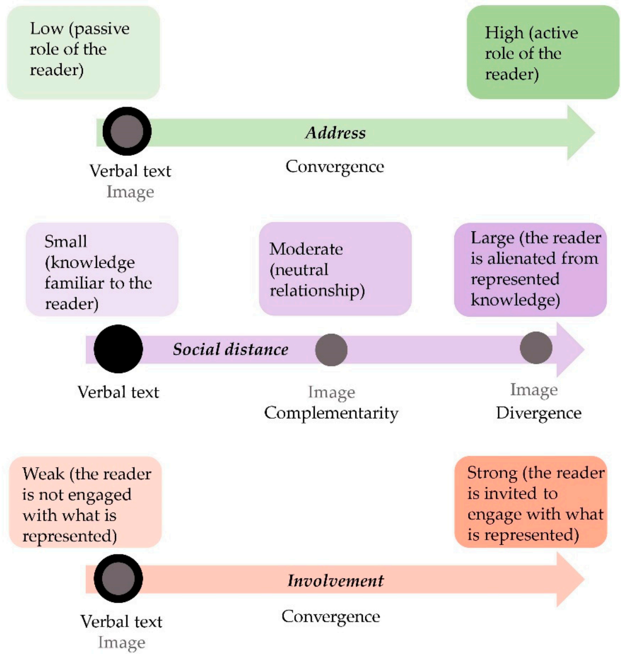

Figure 6. Verbal and visual selections in analyzed texts regarding address, social distance, and involvement.

The socio-cognitive perspective on science teaching and learning advocates that knowledge is not objective or isolated from the learner, but closely related to children's lives [39,48,50]. The analyzed texts do not seem to pay the necessary attention to the interpersonal meanings they disclose through the verbal text and the images they include, but also through the relations between them. The analyzed multimodal science texts for young children tend to promote pedagogically appropriate meanings only in terms of social distance and through the verbal mode, and sporadically through images. This seems to be a paradox, taking into account that preschool children, who are not yet 'literate' in the traditional sense, primarily rely on images in order to 'read' and derive meaning from multimodal texts [108,109]. Moreover, the tendencies of the analyzed material to promote verbal–visual relations of complementarity and divergence do not support young children's understanding. On the one hand, meaning complementarity between different semiotic modes increases the level of complexity in a text, posing challenges in its comprehension [69]. On the other, meaning divergence between different semiotic modes evokes confusion, making interconnection between them problematic [71] and obstructing—instead of supporting—the construction of scientifically adequate meanings [2]. Therefore, the significant number of divergent meaning instances in terms of social distance found in the present study could provoke confusion regarding the position of young readers in respect to the represented knowledge and their relationship with it.

This underestimation of the interpersonal meaning in the analyzed children's science texts might be due to the fact that in such informational texts the focus may lie on the representational meaning which carries the scientific information, i.e., content knowledge. Furthermore, these texts do not seem to adequately take into consideration the consistency between different semiotic modes and promote verbally and visually convergent interpersonal meanings, but rather focus on each of these modes independently—after all, the author and the illustrator of children's books are typically different people. The apparent inattention to interpersonal meanings and the relation between modes might also relate to the informational character of the analyzed texts and their audiences' characteristics, such as restricted relevant knowledge. Thus, the selection of long or medium shot images—implying moderate or large social distance at the interpersonal level—might be considered as most appropriate at the representational level, since it allows the depiction of entities or phenomena in their entirety. Similarly, an oblique angle of image (indicating weak reader involvement) might be preferred so as to provide a general and 'objectified' view of what is represented. Likewise, the represented participants' gazes could be directed to other elements in an image (e.g., systems, and processes) instead of the reader (low address) in order to direct young readers' attention to specific and essential parts of the depicted knowledge.

Furthermore, the linguistic choices identified in the analyzed texts, could be associated with the young age of their intended readership. These selections involve the preference to active voice and parataxis (implying small social distance) and the emphasis on the representational meaning level by reference to the presented information through declarative clauses (denoting low address) and through the use of the third person in verbs and possessive pronouns (promoting weak involvement).

Therefore, semiotic selections apparently driven by an overemphasis on representational meaning have an impact on the interpersonal meanings promoted by verbal text and image, as well as on the relations between them. These in turn allow for the emergence of complementary or even divergent interpersonal meanings from the two modes, considered as inappropriate for young children, or for convergence relations that are incompatible with the socio-cognitive perspective for science learning in early childhood.

These findings are remarkable because informational science books are prevalent mediating tools in preschool education and constitute a significant part of young children's first learning experiences with science concepts and phenomena. The interpersonal meanings promoted by texts such as the analyzed ones largely determine the quality and effectiveness of these learning experiences [30,31,33]. Furthermore, these experiences play an important role in the development of interests [20,110–112]; thus, interpersonal meanings promoted by such texts are expected to influence children's science-related attitudes and aspirations.

One of the limitations of the current study is that it has explored verbal text–image relations regarding dimensions of one of the three different levels of meaning realized in a multimodal text, namely the interpersonal meaning. Further studies could also investigate the interaction between the three different levels of meaning, i.e., representational, interpersonal, and compositional. Specifically, it is of importance to investigate how interpersonal meanings promoted by verbal text or/and images are further strengthened or weakened through messages related to compositional meaning dimensions. For instance, in terms of compositional meaning, the image in Figure 4 through its large size and special position on the right, receives high salience and high information value, respectively. Therefore, it is presented as the most prominent element on the page and as the New, namely the information at issue, to which the reader's attention is directed [25]. In this way, the pedagogically desirable interpersonal meaning (strong involvement) promoted by the image is further reinforced by the image's compositional meanings, contrary to the weak involvement promoted by the verbal text, which is compositionally undervalued through the low salience (small size) and low information value (placement on the left) attributed to it. Similarly, in Figure 5, the distinctive features (bold font, colored letters, and framing) of verbal elements attribute high salience to the verbal text, attracting the reader's attention [109]. Therefore, the pedagogically desirable interpersonal meaning of high address (use of imperative clause and second person) promoted by the verbal text, is further strengthened by the high salience it receives in terms of compositional meaning, counterbalancing the low address promoted by the image and its high salience (large size and distinctive texture of the animal's ear) [53].

A further limitation is that the analysis framework developed and applied in this study as well as the discussion and interpretation of the findings regarding the semiotic selections, were based on specific theories of linguistic and visual communication, the Systemic Functional Grammar [24] and the Grammar of Visual Design [25]. This does not mean that the authors of a text intend to convey the specific meanings or that the readers understand and interpret the various semiotic (verbal and visual) choices in the same way as suggested by the aforementioned theories. Specifically, how preschool children interpret interpersonal meanings promoted by verbal text and images or the relationship between the two semiotic modes in terms of interpersonal meaning when they interact with science multimodal texts, may form critical questions for future research. Last, due to the sampling procedure, the conclusions drawn from the findings concern the population from which the sample was drawn and no attempt is made to generalize the findings to the wider population of multimodal science texts for young children.

9. Conclusions

Our findings indicate that a greater emphasis on the interpersonal meaning and a more systematic analysis of the interaction and interrelation between verbal text and image in science texts for young children is required, aiming at facilitating understanding and supporting them in learning science. Furthermore, the analysis outlined in the present study may have considerable implications for the design, selection and use of multimodal science teaching material.

Concerning the selection and design of such material, attention to verbally and visually convergent meanings is recommended for every interpersonal meaning dimension, especially when a material is intended for very young, emerging readers. In fact, it has been shown that verbal text–image convergence facilitates successful association and coordination of the two modes, thus supporting children's comprehension of multimodal science texts [66]. Additionally, it is suggested that convergence of verbal text and image harmonizes with the socio-cognitive perspective on teaching and learning, which implies that educational material should encourage—both verbally and visually—children's activation, involvement, and familiarity with what is represented in teaching material.

Moreover, the analysis framework used in this study could support teachers in using multimodal science texts in their classroom in order to gradually initiate children in the critical analysis and interpretation of the interpersonal meanings conveyed by means of verbal text, image, and their interrelation in these texts. Children, from an early age, can be supported to effectively read and understand such material and use their relevant competencies to produce multimodal texts with scientific content [12,13,53]. Supporting children in developing multimodal communication competencies is a critical aspect of their scientific (visual) literacy and a broad objective of science education, for which preschool education can lay the foundations [9,41,111,112].

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education sciences

Article

Development of Food Competence in Early Childhood Education

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Abstract: The increase in childhood obesity requires the incorporation of nutritional competence into school programs through appropriate activities, starting in the early years. In addition, it is important to promote scientific and cognitive skills during childhood education. The main objective of this study was the implementation of an instructional sequence focused on the learning of skills such as observation, measurement, or interpretation of data related to plants, their germination, and their growth, as well as its relation with the development of food competence. To do so, a set of differentiated activities, organized into several stages, was designed, starting from simple and concrete situations and progressively increasing in complexity and abstraction. The aims were to express ideas about known fruits, vegetables, and legumes in order to expand them by learning new information through student-centered activities, in which children were able to practice and talk about science. The activities were carried out in a class of 24 students aged 4–5 years and data were compared with a control group. The results revealed that the children were motivated in all the activities, which provided an excellent opportunity to initially develop an interest in science and to start to develop food competence in the early years.

Keywords: early childhood science education; scientific competence; teaching interventions and activities teacher training; inquiry; scientific practice; health; school gardens; sustainability education; cognitive skills; experimental skills

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1. Introduction

During the last 30 years, educational research has tried to justify the importance of developing scientific competence during early childhood education and not to wait for higher courses in which students have greater cognitive abilities, as well as to deepen the training that teachers should receive to promote their development. In this regard, numerous contributions have been made in the field of science education to characterize what it would mean for students to learn to 'do science' in classrooms, that is, to involve them in activities related to abilities; skills; and cognitive, manipulative, communicative, and research strategies of greater or lesser complexity, to transfer to the school level the work methods that characterize scientific activity [1–4]. For example, in Spain, Jiménez and Sanmartí [5] pointed out that in addition to the learning of concepts, compulsory education should promote the development of cognitive skills (scientific reasoning), experimental skills and problem solving, thus promoting the development of attitudes and values of scientific activity. In this way, the transmitted image of science would correspond to current concepts.

Based on these and other contributions and evidence from educational research, the OECD proposed the term scientific competence, which includes the capacity for inquiry linked to specific contexts and the integration of knowledge. This term refers, among other aspects, to the use that individuals make of scientific knowledge to identify problems, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions on science-related issues [6]. Other authors, such as Chamizo and Izquierdo [7], understand scientific competence as the set of capacities that allow knowing, knowing how to do things, as well as being and living with others, in life situations in which one must decide how to act. Franco [8] relates it to 15 capacities grouped into seven dimensions, ranging from the identification of the problem or the formulation of research objectives and hypotheses to the analysis of data, the establishment of conclusions, and the communication of results.

1.1. Teaching Science in Early Childhood Education

To answer the question of why it is necessary to develop scientific competence during early childhood education, we will refer to points of view such as those of Harlen [2,9,10] and Osborne and Dillon [11]. These authors justify the importance of science education from elementary educational levels for two main reasons: (1) the need to create scientifically literate citizens from childhood, so that they can successfully face the challenges of a society steeped in science and technology; (2) its propaedeutic purpose, since this literacy must continue to develop, at least, in the following educational stages of compulsory education. Furthermore, a higher relationship with prior learning experiences in order to explain and interpret other observed phenomena is expected to exist among children who are used to engaging in inquiry-based activities [12]. Therefore, postponing this training to higher levels would not promote adequate development of the aforementioned training dimensions, nor would it take advantage of the impact that teaching based on school research could have during early childhood and primary education on students' attitudes towards scientific subjects. This late introduction could have a negative impact on the choice of future scientific pathways [3,13] and in the aspirations to carry out scientific careers in the future [14]. As Criado and Cruz-Guzmán [15] point out, interest and attitudes towards science are generated before the age of 14, so steps must be taken in the basic stages to ensure quality science education [11]. Several works have addressed the characteristics of the different approaches to children's science education. Among these, it is worth highlighting the review by Ravanis [16] that classifies the proposals into four categories, where not only are the approaches diverse, but the teacher also plays different roles in each one: (1) empiricist approaches, with clear leadership from the teacher who proposes teaching topics directly extracted from the natural sciences; (2) Piagetian approaches, in which the teacher helps, encourages, and facilitates the students' work by recording their choices and obstacles; (3) sociocognitive, with the intention of the teacher to create the right conditions for the active participation of children, allowing them to rebuild their thinking towards a precursor model level; and, more recently, (4) the sociocultural approach, in which the teacher organizes and supports a communication framework and a school environment that allows the emergence and exploitation of elements of human activity in general.

In early childhood education, procedures have been proposed [17,18] that are fundamental for an initial approach of schoolchildren to scientific perspectives in reality [19,20]. Health, the environment and communication are three areas of science important to the lives of citizens [21]. Within these, we will focus on aspects related to food and the environment in early childhood education, since this stage constitutes a key moment in which boys and girls acquire habits and develop behaviors for the future [22]. In this sense, many schoolchildren are reluctant to eat vegetable products and often do not reach the recommendation of five fruits and vegetables a day and exceed the recommended consumption of meat [23]. Therefore, it is necessary to know what the factors are that contribute to the acceptance of food and how this acceptance can contribute to liking a more varied diet in childhood [24].

1.2. Development of Healthy Feeding Learning in the Early Years

The knowledge regarding how young children think about food is very scarce [25], since the way in which children learn about healthy eating is extremely complex [26]. In addition, there is a lack of empirical research on the formation of scientific concepts between 0 and 3 years. This can be attributed to two factors: on the one hand, the limited verbal skills of students at this age makes it difficult to collect information, and on the other hand, this stage—historically understood as childhood—used to be exclusively focused on care. Only recently has it started to be considered in relation to formal education, and it has become possible to introduce research considering infant children capable of acting as 'scientists' [27]. Children learn about food as they develop perception, cognition, behavior, and experiences with it. Two effective techniques for learning about food, especially for younger children, are familiarization through repeated exposure to its taste, texture or appearance, and observational learning by choosing foods by mimicking others' eating behavior [28]. In familiarization learning, the evaluation of a stimulus increases after repeated exposure, which is reflected in the selection of those foods that have been repeatedly experienced in their environment. Thus, if children at early ages have frequent experiences with healthy foods, they will be more likely to promote the acceptance of these options in the future, even among many high-energy foods. Observational learning arises due to the opportunities for children to feel influenced by the eating behaviors of others when they eat in social contexts, so it can have positive or negative effects, depending on who their food models are. For example, the consumption of unhealthy food will promote the intake of these foods in children, with negative effects on the quality of the diet [29]. Data have shown that preschool-aged children's food preferences and consumption are strongly influenced by those of other children. Exposing the children to peers who were selecting and eating certain foods not preferred by them initially was enough for them to change their selection after observing their peers, even in the presence of an initially chosen food. This shows that peer models were effective in altering preferences, for example, for preschoolers' vegetable consumption at lunch [30]. Actively positive social role models, provided by adults and peers, can be effective in promoting healthier eating, so the introduction of a new food could be conducted initially in a moderated way through brief repeated tasting of the food in a positive social context [31]. Conversely, foods associated with negative social contexts may become less preferred or rejected [32]. Due to the coercion and interpersonal conflict that the forced consumption situation implies, the exact opposite occurs, and children will be less likely to consume the desired food in the future. Therefore, if the child does not want to eat the new food, it is best not to force him to do so and to try again at another time.

Other techniques for setting food preferences are associative learning through the introduction of flavors and food categorization. In the first one, an initially neutral (conditioned) stimulus begins to elicit responses after being repeatedly introduced together with a significant (unconditioned) stimulus. In the second, what a child will be willing to consume will depend on their ability to recognize the items on their plate as familiar specimens of that type of food, and therefore, the categorization of foods could have an influence on their taste for healthy foods [28].

With age, factors such as peers and the availability of food continue to shape the food preferences and behaviors of schoolchildren [33]. However, from preschool to the beginning of primary school, children's knowledge about food improves and significant differences can be seen between them [26]. There is a change in children's thinking about preferences, appropriate situations for eating fruits and vegetables, and wholesomeness. The importance they attach to the attributes that determine whether or not a child likes fruits and vegetables evolves in parallel with children's cognitive development, as well as their understanding and reasoning about health. The most important determinants of taste shift from appearance and texture attributes in 4- and 5-year-olds to more functional properties in 11- and 12-year-olds. Therefore, cognitive development parallels changes in the importance given to the attributes that determine whether or not a child likes fruits and vegetables, increasing their knowledge with age, along with development in the level of abstraction in reasoning and a better understanding of the health benefits of food. This finding could be of interest to those who design appropriate curricula and activities for the development of nutrition education in young children and should be incorporated into programs aimed at increasing the long-term intake of fruits and vegetables in children. Thus, using different preparation methods depending on the wishes of each specific age group, we could change children's fruit and vegetable preferences and, consequently, their intake [25]. These results are consistent with previous studies about the level of knowledge and thinking about the feeding process of children in the preoperational and concrete operational stages, which, according to Piaget, show characteristic differences, for example, in the use of symbolic thinking and in the skills required to demonstrate two-way and systematic thinking, as well as to analyze problems from multiple perspectives [34].

Children in Piaget's preoperative stage (2 to 7 years) are not yet fully developed cognitively and learn by imitating, investigating, asking questions, and comparing and classifying things around them. This is the stage when children learn basic concepts and begin to acquire the ability to think. Consequently, nutrition education can be difficult in the preoperative stage because children of this age have difficulties in understanding the relationship between nutrients and food, as well as the effects of food on the body. Therefore, at this stage it is not easy to understand and explain abstract concepts such as the definition of health or the importance of nutrition [22]. In general, classifications are commonly based on specific groups, such as drinks, main meals, and foods eaten together, rather than on abstract ideas such as constituent nutrients [35]. Furthermore, children of this age make appropriate groupings of fruits and vegetables, meat and derivatives, and sweet foods. Preschoolers begin to establish weak relationships between food and health and to recognize the need to maintain a varied and balanced diet, which is reflected in the food choices and comments they make. Thus, young children can indicate whether or not they like the taste of a product, but not identify the specific taste. For example, 4- and 5-year-olds know and can properly use the taste of salt. When talking about sugar and salt they often comment on the similarities between the two substances in terms of appearance, stating that both of them are added to foods so that they taste 'better' or are 'bad', often mentioning teeth in this context [36]. However, they are not capable of doing so with other basic flavors.

Older children have a better understanding of the four basic tastes and are consequently more specific when discussing food tastes. At the age of 4 or 5, they use concrete and simple 'rules' to classify products as healthy or not. The most popular justification rule is usually food color association, such as 'it's healthy because it's green', which can lead to misclassifications. Another argument is to link food groups and health, ('it's fruit and fruit is healthy') or preference ('it's healthy because I like it'). A surprising finding is that 4- and 5-year-olds argue that food is healthy because it tastes good, so it could be that young children associate healthy with tasty through the connection term 'good'; tasty food is good, just as being healthy is good too, until, at a certain age, the differentiation arises that not all healthy foods taste good [25]. At the age of 6, they present notions about the health consequences of food; know that specific nutrients, especially fats and sugar, have effects on the body; group foods as healthy or unhealthy and their selections are consistent with health views; and recognize that foods that are sweet or contain sugar or fats should only be eaten in small amounts and 'are bad', whereas those that contain fiber and vitamins are 'good' and 'healthy' [36,37].

It is not until the concrete operational stage that children include the presence of a specific nutrient to justify the classification of products as healthy or not, in addition to also mentioning 'the family says so' or 'I know it' [25]. The research carried out by Contento [38] on how children think about food and eating revealed that in the preoperational stage they did not distinguish between food and snacks, whereas children in the concrete operational stage did. In addition, the former thought that the ingested food entered the stomach and did not change in the body, whereas those of a specific stage indicated some type of change. The children in the preoperational stage were able to mention healthy foods, but not to justify this, and those in the concrete operational stage stated that food makes you strong, healthy, and grow, but were not able to explain it either. Schoolchildren between 7 and 11 years of age still make arguments that could lead to the restriction of potentially beneficial products, such as apples, because they are acidic or to consume unsuitable products, such as white chocolate instead of dark, considering that the second is not good only because it stains the teeth. Although they make correct classifications, sometimes the reasons used to do so are incorrect [35].

Therefore, the significant differences in global knowledge about food may reflect Piaget's stages of cognitive development and serve as a guide for the nutrition education of preschool children. Understanding that children's cognitive development is important for understanding and learning about the world around them would be helpful in designing effective and developmentally appropriate nutrition education in childhood [22]. Older children have a higher level of abstraction and are more aware of the health benefits of a good diet. Younger children have little understanding of the connection between food and the effect of fat intake and weight, which may contribute to current rates of childhood obesity [26].

1.3. Acquisition of Nutritional Competence during Early Childhood Education

The younger the children, the less established and externalized are their eating habits, so interventions in preschool children may be more effective than those in older ones. In addition, to increase its effectiveness, it is important to involve parents and caregivers, as well as train them to know the inherited habits in the eating behavior of children [31]. However, even though child nutrition education improves the behavior and lifestyle of preschoolers, nutritional interventions in schools with very young children (3 to 5 years old) are very scarce. Some studies aimed at developing the knowledge of healthy foods in parents of young children (5 to 6 years) [39] or promoting healthy behaviors among adults and preschool children [40] have shown that targeting the close environments of children achieves good results. The most effective school interventions are those that include the family and focus on realistic intermediate goals, for instance, linking changes in knowledge and attitudes towards diet and physical activity as early indicators of future improvements in adult cardiovascular health. In a study carried out in [41], parents and children were provided with a comprehensive nutritional education program for behavioral weight management and were encouraged to increase their intake of fruits and vegetables or decrease the consumption of fat- and sugar-rich foods. It was observed that directing the intervention to the intake of fruits and vegetables also resulted in a lower consumption of fats and sugars, whereas focusing on the reduction of fats and sugars did not improve the intake of fruits and vegetables. To avoid the childhood obesity epidemic, it is necessary to combine many strategies in schools, communities, clinics, workplaces, and homes [42].

A good opportunity to promote 'good habits' and support the effort made by teachers is to encourage the participation of families in the classroom. In this way, the commitment of all parents would help to promote nutritional knowledge and behaviors in the short and long term among preschool children and their families [43]. In addition, strategies focused on improving dietary and physical activity behavior must be combined with other critical aspects of an intervention program to be effective [44]. Likewise, it is recommended to include educational materials, films, and books that contain the widest variety of healthy foods as possible [31]. However, explaining nutrition and health to children, using terms that are too abstract for them to be understood and acquired (vitamins, minerals, nutritious foods, digestion, and risk of disease) is inappropriate. Therefore, incorporating Piaget's theory into nutrition education at an early age could have a lasting effect on eating behavior [22].

It is essential to promote adequate teacher training prior to the implementation of strategies to improve child health [45], since teachers are responsible for empowering students to interpret phenomena and to relate and connect knowledge, above all, promoting initiatives that allow them to extract the ideas that give meaning to the natural world [46]. España et al. [21] presented a frame of reference around seven dimensions for students to be competent in developing healthy habits and lifestyles regarding their diet. Among these, we can note knowledge about food; how the body works with regard to nutrition;

cooking, growing, and making food; buying food; eating in company; physical activity; and rest. Other studies suggest participation in cooking classes and games, along with individual guidance to optimize diet and physical activity habits for children aged from 2 to 6 years [47].

A classroom curriculum that includes hands-on activities that emphasize gardening and nutrition, operationalized through strategies such as interactive stories, songs, dances, container gardening, snack preparation, and taste-testing activities promotes the learning of the origin of fruits and vegetables through active and observational learning, increasing the preference and intake of these foods among preschoolers. The children brought their plants and other materials they made home and shared them with their families, fostering dialogue between parents and children. In addition, at the end of the program, the parents were invited to an event in which the children presented songs and dances learned during the program [48]. This shows that the teaching activities developed in school gardens can relate science content to real-world contexts as relevant as the production of plant foods, also addressing the promotion of healthy eating habits [49]. The school garden as an educational resource allows teachers to develop with their students the skills related to scientific processes, such as making observations, classifications, measurements, predictions, or performing the identification of variables, among many others [50,51]. As a consequence, more and more educational centers are increasing their interest in having a school garden [52]. The self-production of fruits and vegetables is very useful for students since it involves activities that are not usually part of their daily experience: doing work outdoors, sharing natural resources, enabling cooperative work, and improving relationships between boys and girls [51,53,54]. The work of students and teachers in school gardens involves real practical activities based on experience, with which the learning of the curricular contents is facilitated and the skills typical of scientific work are put into practice, such as observation, the verification of ideas, as well as the perception and exploitation of proposals and actions [55].

Already during the 20th century, a similar resource, school preserves, was used to introduce a wide variety of practical knowledge and prepare students for life in a utilitarian sense. In addition, they allowed the teaching content to be related to the child's environment, organizing the school curriculum from a globalization and integration perspective that provides the opportunity to carry out research and promote curiosity, enabling the direct observation of phenomena and the acquisition of critical thinking and spirit [56]. Therefore, the use in educational centers of school gardens allows teachers to turn them into a very valuable educational space [49] and constitutes an opportunity for the classroom implementation of active and experiential methodologies [57]. With these gardens, students learn science by doing science through experimentation, developing knowledge, skills and attitudes typical of this field of knowledge [50,58].

1.4. Proposal Justification

As mentioned, it is essential to initiate students in the development of scientific competence from an early age. Through direct experiences, children interact directly with objects, which allows them to learn not only scientific content but also how knowledge is built. Specifically, if the intention is to promote familiarization with fruits and vegetables, it is necessary to offer students opportunities to learn about their diversity and promote a taste for them through appropriate sequences of activities for early childhood education.

Active teachers of 3- to 6-year-old children from different schools have expressed the importance of identifying preconceptions when teaching science in the early years. It is essential that lessons begin with an activity designed to identify preconceptions, as well as ending with another to summarize and discover if the initial predictions were correct [59]. Listening to what students are saying, even when answers are unexpected, is essential to select appropriate and meaningful activities that promote experiences that can be carried out directly by students and, whenever possible, to accommodate children's interests and develop their thinking [36]. Meanings can be better shared if we have a specific material to refer to, avoiding different interpretations of words because we have not experienced them directly. Starting from a concrete fact, dialogue can be promoted in the classroom through contact with reality. For example, to introduce the conditions that a seed needs to germinate, a good option is to start by talking about the different criteria that each child chose to make a bean germinate better at home. In this way, an everyday phenomenon until now is observed from a scientific point of view. This initial challenge promotes motivation by having to make active individual decisions to solve a problem, and finally, the sum of contributions will generate collective knowledge [46].

In school, when children begin learning new content about food, they already have their own ideas from their pre-school experience. Therefore, the introduction of new knowledge must be carried out through activities organized in a logical way that start from those ideas. Herein, we propose an educational intervention to promote the taste for healthy foods (fruit, vegetables, and legumes). The sequence consists of a set of differentiated activities that start from simple and concrete situations and progressively increase in complexity and abstraction [35]. This process allows a model to be built based on four key moments [60,61]:

(a) Verbalization of the initial models, so that the children formulate their own points of view (What do I know? What do I think? What do I feel? What do I do?) and recognize the objectives of the work through the analysis of very simple and concrete situations, close to the experiences and interests of the students. In addition, by sharing, children can be encouraged to overcome the self-centeredness of this stage by knowing that other children may have different points of view. It is necessary that the environment generated by the teacher be adequate and encourages children to be safe to verbalize their own thoughts.
(b) Activities to introduce new elements, relationships, and variables to identify new points of view and to confront reality (Are there other ways of seeing, thinking, feeling, and acting?). It is important to define the concepts and relationships between old and new knowledge. Depending on the content to be taught and taking into account the knowledge and interests expressed by the children in the previous stage, different methodological proposals could be included. In relation to feeding, educators will replace the existing schemes of children with the introduction of newly learned foods. As a result of assimilation through experience, children will gradually incorporate and adapt new concepts of nutrition [22].
(c) Structuring activities of the built models. It can be considered that learning has occurred when a child is able to communicate the elaborated models. For this reason, it is necessary for each child to personally elaborate their way of expressing knowledge, generalizing the new models built and contrasting them with those of other classmates. The way in which each child synthesizes the same learning and how confronts it with others is very diverse.
(d) Application activities of the developed model. The purpose of this is to facilitate the transfer of acquired knowledge to different situations, that is, to make it meaningful (How to apply new ways of seeing, thinking, feeling and acting?). Furthermore, its purpose is for children to be aware of what they have learned and to consolidate the new ideas.

We can conclude that, in order to design an adequate didactic sequence to teach science at this age, it is necessary for students to act personally and learn by observation, experimentation, classification, etc. These activities therefore require sufficient space and time according to the stage. Children learn best by doing, so it is important that educators promote the active participation of children in nutrition education, including drawings or games with nutritional content [22]. Considering the influence of social learning in this stage, activities that are carried out together with other classmates should also be incorporated. In this way, in addition to promoting the construction of new models, the development of social and communication skills is facilitated both by expressing their ideas orally and by means of drawings or diagrams, which are beginning at this age, and should progressively incorporate the characteristic language of science. This learning is guided by the teacher, who formulates the appropriate questions that should preferably be open, contextualized, and clearly formulated [62]. The questions must focus on observing the facts of the world in such a way that, taking into account the cognitive capacities of the children in the preoperative stage, they facilitate the development of the initial models towards others that are more intellectual, complex, and of a more general nature [63].

Through conversation and observation, we can also incorporate different forms of evaluation, such as self-evaluation, which will promote making children aware of what they have learned and self-regulating their learning [64]. In the preoperative stage, instead of using abstract nutritional concepts (nutrients that cannot be seen or touched), concrete statements and examples should be used. Choosing relevant activities (drawing, reading, discussion, hands-on activities) along with information that children already have will facilitate the acquisition of desirable nutritional concepts. In addition, explanations, classifications, and demonstrations can be used to help children remember what they have learned [22].

1.5. Specific Objectives of the Work

The global proposal is the development of competence in nutrition by preschoolers. Specifically, the work focuses on the following specific objectives:

- To initiate early childhood education students in the development of some of the most basic scientific skills in the context of nutrition, and more specifically of vegetables, such as making observations, manipulating simple instruments, putting into practice the design to be made, collecting data, and verbalizing their expectations and results.
- To understand the difficulties of children in early childhood education in carrying out basic scientific skills and propose guidelines for their development among early childhood education teachers.
- To promote the development of food competence through familiarization with fruits, vegetables, and legumes, as well as their care and the purposes of their cultivation.

2. Materials and Methods

2.1. Sequence of Activities

The activities developed to promote competence in food and care for the environment have been structured in a series of stages that are included in Table 1. Regarding the competence in food, the dimension that is analyzed in this study is the one related to the cultivation of fruits and vegetables.

Next, the activities in the stage of introducing new information (stage 2) are described in detail, along with images of the results. In this type of task, it is necessary for the teacher to ask good questions that allow students to carry out observations and scientific investigations based on data collected during practical experience, as exemplified in this text. The first activity of this phase is a proposal for early children to begin with the perceptual knowledge of the plants. The purpose is that the students know the diversity of seeds and understand that, because they are different, they will not grow in the same way and will give rise to a wide variety of fruits, vegetables, and legumes. This will allow us to expand the taste for these foods by learning about new varieties that can be introduced into our diet. The contents addressed are the following:

- There is a great variety of seeds.
- The seeds germinate and give plants.
- Different seeds will give rise to different plants (beans, lentils, chickpeas, broad beans, peas, and chard)
- Techniques for sowing seeds.

In the second activity in the same stage, 4- to 5-year-olds are initiated to observe how fruits, vegetables, and legumes change over time. Although the goal of this activity is not to make children aware of the passage of time, recording the days when changes occur is an approximation of understanding the cycles of the plants they are caring for. Specifically, the contents addressed are:

- Changes that occur in the seeds during the germination process and its sequence.
- All plants have roots, stems, and leaves.
- Techniques that facilitate observation and data collection.

Table 1. Stages, objectives, and activities of the didactic proposal on the teaching of nutrition in early childhood education.

Stages of the Didactic Sequence	Objectives	Performed Activities
Stage 1: Verbalization of the initial models (initial brainstorming activities)	Express ideas about the new content to be learned. Be aware of the variability of classmate's opinions. Motivation to be interested in the new learning.	Go to the garden and talk about the plants to ascertain children's preconceptions through questions formulated by the teacher. Carry out discussions to find out the tastes for fruits and vegetables among the whole group. Stories or songs that arouse interest in schoolchildren. Observe facts or images. Promote the participation of families by sending fruits and vegetables to be eaten and seeds of legumes to be grown at home. Ask an open question, such as, How can we have more variety of fruits, vegetables and legumes?
Stage 2: Activities to introduce new elements, relationships and variables (confrontation with reality)	Expand or transform initial ideas by learning new information Talk, practice, and think about science	Practical observation/research work (activities 1, 2 and 3). Participation of families in the care of the plants, seeds, etc., that the schoolchildren bring home. Reading of materials adapted to the cognitive level (stories, webs). Games. Approach to situations or problems. Information consultation (books, experts, internet).
Stage 3: Structuring activities of the built models (reflection and conclusions)	Be aware of new learnings when comparing them with initial ideas. Co-evaluate learning with colleagues.	Draw or talk about new ideas with the whole group. Synthesis of what has been learned through a summary and reviewing all the data collection tables of the germinations.
Stage 4: Activities of application of the elaborated model (use of what has been learned).	Use the knowledge learned in new situations and contexts. Consolidate new ideas. Check the learning functionality. Talk, practice, and think about science.	Draw what we have learned using different art techniques (see annex 3) Games, songs, poetry (see annex 4) Order the logical sequence of the life cycle of a plant (see annex 4) Prepare a presentation to make to other classmates.

The materials needed for the implementation of this activity are different seeds (beans, lentils, chickpeas, broad beans, peas, and chard), pots or other containers, soil, water, and droppers or small bottles of water with a perforated cap. It is therefore necessary to make a series of concrete decisions with the students about the design of the experience, data collection, and analysis of results (choose the seeds, the container where they are placed, the place where it will be carried out, the environmental conditions, etc.). Next, the seeds are sown in the selected container and covered with soil, and water is poured until the soil remains moist but not flooded. The largest seeds (chickpeas, lima beans, and beans) should be soaked for at least 10 h before the activity. The students make observations and annotations on the data record sheets for about 15 days. In order to guide scientific observations, the teacher asks several questions during the experience:

a. How many plants have come out of each species?
b. How are they alike and how are they different (plant color, number, size and shape of the leaves, height, etc.)?
c. Are there differences between plants of the same type?
d. Have they all germinated at the same time? If not, what could be the cause?

To observe the process, seedbeds, which facilitate direct observation of the changes, are used, and each child cuts the cotton necessary for their own assembly. The cotton should be kept moistened but never flooded throughout the activity. It is convenient to use at least two containers with different seeds and try to rotate so that all the seeds have approximately the same amount of illumination. In this activity, although the technique does not allow many variations, there are some decisions to be made by the group such as the type of container and seeds, moments of observation, etc. Once the activity has been carried out, the data observed are recorded in the table (Figure 1). Subsequently, children interpret the data obtained and reflect on the similarities and differences of the changes produced in the different seeds.

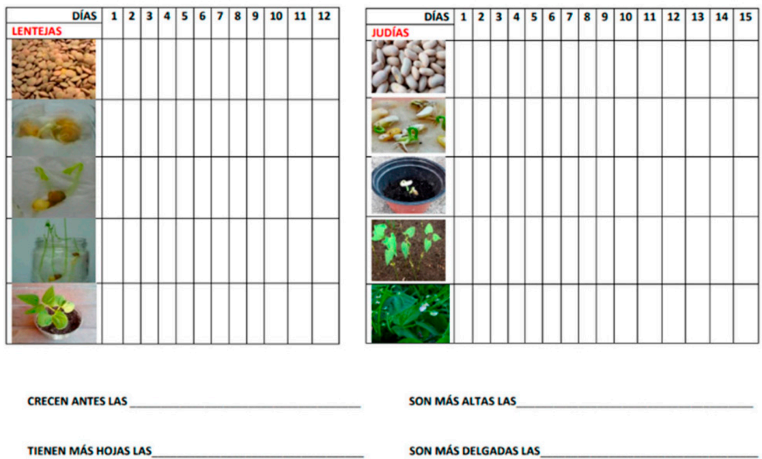

Figure 1. Data recording table provided to children. (lentils/beans . . . grow before . . . . . . have more leaves . . . . . . are the tallest . . . are the thinnest).

The intent of the next activity from the same stage was that the students observe how the plants interact with the environment and take from it all the elements they need. To germinate, a seed requires water and air. It is also sensitive to temperature; however, light is not usually a factor that influences the process. There are also internal factors in the seeds (lethargy, longevity) that could influence their germination. In the early childhood education stage, the purpose is not to systematically investigate the environmental conditions that influence seed germination but rather to discover some of them. In the classes of 4- to 5-year-olds, we can provide students with experiences that facilitate the construction of that knowledge. The contents to work on are:

- The influence of some environmental conditions for the seeds to germinate.
- Initiation of research design.

The questions raised by the teacher during the activity are:

- How would you check if the water affects the germination of the seeds?
- How would you check if the light affects the germination of the seeds?

The experiment must specify both the variables that will be kept constant (container, number and type of seeds, lighting, place where it will be carried out, type of land where the seeds will be placed, etc.) and the values of the variable that are modified (watering twice a day or week/watering with the same amount of water once a day or week).

2.2. Sample and Context

The present research, which was manipulative and experiential, was carried out with an experimental group composed of an intentional non-probabilistic sample of 24 students (14 boys and 10 girls) aged 4–5 years that attended a school in a medium-sized capital city of Spain. In addition, a control group consisting of 14 students (7 girls and 7 boys) participated, with the same contents implemented, although the methodology and resources used were more traditional, based on predesigned materials and classroom work. The teacher set the working topics, proposed and guided the experiments, and exerted a leadership role. Two years ago, the school advised against the use of standardized textbooks in early childhood education. Since then, the teacher responsible for the group has provided their own educational material and has not been required to complete a specific book. Both teachers of the experimental and control groups had more than 20 years of experience in the profession and great dedication to their work, and it was the second year that they had worked with these students. In our study, the sequence was designed by the teacher of the experimental group, paying special attention to the suggestions made by the authors of this work. These activities were part of a project to promote healthy habits at school, which encouraged children to consume fruits and vegetables. For example, when they were 3–4 years old, they made fruit salads to learn about autumn fruits in a tasting activity that involved their families in the classrooms of the experimental and control groups.

Based on the teaching schedule, both teachers agreed on the objectives to be achieved and the contents to be developed (Table 2), although they followed different teaching approaches with greater use of the school garden and the selected pedagogical manipulative material in the experimental group. Despite having difficulties with respect to personal and material resources, the teacher of the experimental group opted for the aforementioned approach because the preschoolers showed a great interest in research and the natural environment. Moreover, this proposed instructional intervention was an attempt to create the conditions for children's active involvement with an aim of reconstructing their thinking at the precursor model level from a perspective close to the sociocognitive approach. Thus, it would help children to interact with the selected pedagogical material in appropriately designed environments [65,66].

The implementation of the designed sequence of this study took place in the last trimester of the 2020–2021 school year. The center has a school garden, traditionally used by older students; however, the children in early childhood education showed great interest in getting to know the garden and participating in it, so for the first time it was included as part of the children's programming. At first, the decision was made to visit the garden to help clean the herbs and collect some vegetables, legumes, and fruits that were taken home to taste and grow with the families. Later, the activities were aimed at investigating seeds of different fruits and vegetables, germinating legumes, and planting edible sprouts in their own seedbed to see how they grow and to learn about the purposes of their cultivation once transplanted into the school garden.

All the activities were carried out in a practical and manipulative way, alternating between the classroom and the garden. The activities implemented in class were developed in four groups of six schoolchildren each. However, visits to the school garden were organized according to their availability, as there were usually students from higher grades using the garden. In addition, the coincidence in the schedule with the presence of a support teacher was used to carry out the activity with half of the students at a time. The intention was that students would enjoy natural resources and the outdoors, especially this year after having suffered enormous restrictions as a result of the pandemic.

2.3. Evaluation

For the learning evaluation of our proposal, we considered the techniques and instruments recommended in experiences for formative and shared evaluations in early childhood education [67]. Thus, photographs and video recordings of the sessions were collected. In these, the students can be observed carrying out the activities in small groups supervised by the teacher, whereas the rest performed another task. We also transcribed both the conversations held between the teachers and the students and the discussions between students. Moreover, both the children who did not participate in the program (control group) and the participants in this study were interviewed to compare the acquired competencies. The questions were agreed upon by all the study authors and were tested with 3 students to assess their suitability.

The evaluation of the teaching process was conducted through a self-reflection of the classroom teacher, taking into account the objectives achieved and the difficulties encountered, thus proposing improvements for future years.

Table 2. Objectives, contents, and assessment criteria corresponding to the last trimester of the course, which correlated to the sequence of activities.

Objectives	Contents	Assessment Criteria
Observe the natural phenomena that occur in spring. Name and differentiate the elements of the soil between living and non-living beings. Observe and describe plants and their characteristics. Identify the life cycle of a plant graphically and in an orderly fashion. Acquire habits and attitudes of well-being by carrying out activities related to nature. Place importance on reuse through its effective practice. Observe and manipulate the objects and materials present on the soil. Perceive the similarities and differences between objects based on their color, shape, and size. Experiment with and use different materials to carry out plastic activities: recycling materials, thick waxes, paint, papers, dies, stickers, glitter, colors, patent leather, etc. Use different basic techniques: remove dies, paste, tear papers, cut out, draw, color, stamp, remove and paste, and so on. Find letters and/or syllables within a word through a game. Extend the vocabulary about the soil and its elements. Acquire essential norms of communicative exchange: listen carefully. Build the notion of quantity of 5. Start the numerical decomposition of 5. Exercise the spelling of numbers up to 5. Begin in the orderly counting of ordinal numbers up to 5. Be able to count up to the number 15 in order. Get started with the numbering and calculation of 5 units. Adopt hygiene measures during the proposed activities. Respect and take care of the environment and the elements that compose it. Explore the soil and the elements found in it through the senses. Demonstrate initiative to function autonomously in the environment. Acquire autonomy through their activities and actions.	Observation of the phenomena of the natural environment that occur in the spring. Soil elements: living and non-living beings. Observation of plants and description of their characteristics. Identification and serialization of the life cycle of a plant. Plant elements found in the soil. Enjoy doing activities related to nature. Reuse objects in the construction of new objects. Expansion of vocabulary about the soil: insects, small animals, stones, roots, etc. Basic rules of communicative exchange: listen carefully. Simple techniques of plastic expression: painting, coloring, removing and pasting dies, cutting and pasting, decorating, etc. Materials for plastic expression: thick waxes, colors, dies, stickers, paint, markers, glitter, recycling materials, etc. Importance of letter order: attention/observation games. Expansion of vocabulary about the soil: insects, small animals, stones, roots, etc. Narration of short stories from a sequence of images: growth of a plant. Numbers: quantity, spelling, and decomposition. Count to 15. Initiation to addition. Exploration of the soil and the elements found in it through the senses. Autonomy: actions and activities that they can now do alone. Initiative to function autonomously in the environment.Attention and effort during the performance of the various activities. Hygiene and safety measures during the observation and manipulation of objects and elements of the environment. Respect for the surrounding spaces and care for their elements.	Is able to order a sequence according to its timing. Difference between true and false according to established criteria. Solve logical series. Starts with counting ordinal numbers. Decompose numbers up to 5. Recognize and identify amounts up to 5. Identify and practice the spelling of numbers up to 5. Is able to count in order up to 15. Solve simple sums. Observe the natural phenomena that occur in spring. Know the names of small animals that live in the ground: worms, spiders, ants, etc. Is able to describe the main characteristics of plants. Order the logical sequence of the life cycle of a plant. Recognize what elements of plants are in the soil. Enjoy activities related to plants. Recognize the importance of reuse. Places importance on the reuse of materials. Experiments with and discovers some elements that make up plastic language (line, shape, color, texture, space). Uses different basic techniques: taking dies, pasting, tearing papers, cutting out, drawing, coloring, stamping, taking out and pasting, and so on. Experiments with and uses different materials to carry out plastic activities: recycling materials, thick waxes, paint, papers, dies, stickers, glitter, colors, patent paper, etc. Discovers syllables within a word through games. Recognizes the importance of the order of the letters that make up a word. Tells short stories from a sequence of images. Knows vocabulary about the soil and its elements. Listens carefully at different moments of communicative exchange. Distinguishes and classifies objects based on their characteristics of shape, color, and size. Is able to push yourself and pay more attention during activities. Shows hygiene and safety skills and attitudes in observation and exploration activities. Respects and takes care of the environment and its elements. Takes care of and uses the objects and spaces in the classroom appropriately. Manipulates and explores the ground through the senses. Develops with greater autonomy in their environment.

3. Results

In the following sections, we differentiate between the students' productions and the opinions they expressed during the work in the following stages: (a) seedbed preparation; (b) plant growth, measurements and data collection; and (c) establishment of final conclusions by students after analyzing the information. Finally, we analyze the boys' and girls' answers to different questions related to the acquisition of basic nutrition skills for this stage (d) and include the self-assessment of the teacher after implementing the sequence of activities in class (e).

(a) Seedbed preparation

During the development of the activities, the children were not asked to be silent, but were free to speak and move around the classroom. However, there were no misbehavior situations, and the teacher did not feel nervous with this format. Each had individual material to cut cotton, sow seeds, water and transplant from the seedbed of the group. In Figure 2 we show images of the students' scientific work.

Figure 2. Seedbed preparation.

During the assignments, we wrote down the conversations of students and teachers about the work done. Certain doubts about the influence of light on the germination of the seeds and which was the most suitable place to place the seedbed were observed. Thus, Table 3 collects some of these conversations recorded during the development of the activity.

Table 3. Fragments of conversations between the teacher and the students throughout the seedbed preparation and plant growth of the educational intervention.

Teacher	Student
Where do we put it?	In the closet
And if you don't get the light, what happens?	Does not grow
What are you doing?	Transplanting the pot
And what have you planted there?	Lentils

From the information collected in Table 3, we can observe that the students were expressing their ideas when answering the questions formulated by the teacher, for example, how the absence of light affects the growth of plants. We verified that the students were fully aware that they were working with plant seeds (lentils) and, although they may think that the seedbed will be more protected in a closed space (closet), they also believed that light was needed for germination, confusing this process with nutrition, a difficulty that has already been identified in other studies among primary education school students [68].

(b) Plant growth, measurements, and data collection

In the subsequent stages of the work, the students continued working under the same grouping conditions as in the previous stage. They also had at their disposal the individual material for watering, transplanting, measuring with a ruler, and collecting data. In addition, at this stage, they had a table to record the results of the growth of the plants throughout the days and, in this way, to establish comparisons between the plants of the same seedbed and the growth of the plants of other groups. Students made measurements using the ruler, collected data, and wrote them down in a table to compare the plants. In Figure 3 we show the germination of the seeds and the growth of the plants of some of the work teams.

Figure 3. Plant growth.

One aspect of great interest in our work was verifying the need to begin in these stages of early childhood education with tasks, according to this level, that develop competence in measuring and recording systematic information. In Figure 4, we show images obtained in the class on the measurement of plant growth, as well as the recording of growth information over time.

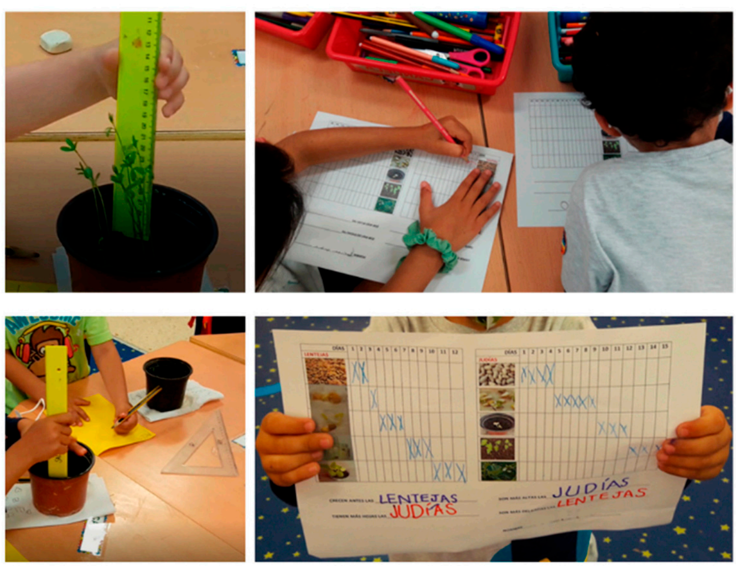

Figure 4. Plant growth measurements and data collection.

The analysis of the students' work and the recording of the conversations between the students and the teacher revealed some interesting aspects about the difficulties in making measurements and recording the information in tables. In Table 4, we include a selection of these conversations from the visualization of the videos and the answers collected. As shown in Table 4, it can be established that the activities promoted the learning of skills such as measuring the plants using a ruler, placing the zero at the same point, making comparisons between the different plants, and relating growth with planting time.

Firstly, we highlight the relevance, as it cannot be otherwise, of the importance of the measure to be able to specify some colloquial expressions of the students about growth. These were usually expressed with surprise at the growth, stating terms such as "it has grown a lot" or "it is very big", and they claimed the need to have a ruler to assess this growth and to be able to establish comparisons. In this regard, we also note the difficulties in using the ruler to make length measurements and, especially, the difficulty in making the zero of the ruler coincide with the point of origin of the plant in the pot. On the other hand, we also appreciate the students' interest in collecting the observed changes in plant growth in a data table, which allowed us to contrast the data between the teams. The teacher was very insistent on this aspect and the students generally followed these instructions.

Table 4. Fragments of conversations between the teacher and the students throughout plant growth, measurements, and data collection in the educational intervention.

Teacher	Student
What is the length?	17
Hi Pepe, what are you doing?	To size
Have your plants grown a lot?	A lot
How much? How high?	11
Well, write on your sheet, have they grown a lot? In how many days? Then we will look at it on the table.	A lot
And how much have your plants grown? Have they grown a lot or a little? Well, from last week to today it has been at least 4 cm. Well, write it down and we will check it later. You planted them after the others.	Little, up to 9.
(The teacher gives him the rule) Why is it better inside?	Not like that, it's better inside! (No answer) A 1 and a 3.
And how are your plants? Have they grown a lot or a little?	A lot
Much? Let's see, how much? Take (He gives him the ruler). Put it like this, here is the zero. Write down that number.	(write it)
And how are yours? Quite large, just like Daniel's.	A little big
It is wet? Well then add a little more	(While watering) 'Already or more?' No'

(c) Establishment of final conclusions by students after analyzing the information.

Collecting the information obtained with the video recordings of the classes and the analysis of the conversations allowed us to identify the evaluations that the boys and girls of our study population made about the diversity of data obtained and how they tried to justify that diversity of data. In Figure 5 we show some of the students' drawings once the tasks had been completed, in which they recreated their images of the work done.

Similarly, in Figure 6, we show other drawings and murals made by students who tried to summarize the experience. It should be noted that these works reflect the stages in the growth of plants from the moment they germinate until the end of the data collection in the classroom, allowing them to order the logical sequence of the life cycle of a plant.

Throughout this stage of the work, we verified the surprise that many of the students experienced due to the disparity of results found, with respect to the growth of plants. In Table 5, we show some examples of teacher and student conversations that reflect this variety of data.

Figure 5. Drawings of what children had learned using different art techniques.

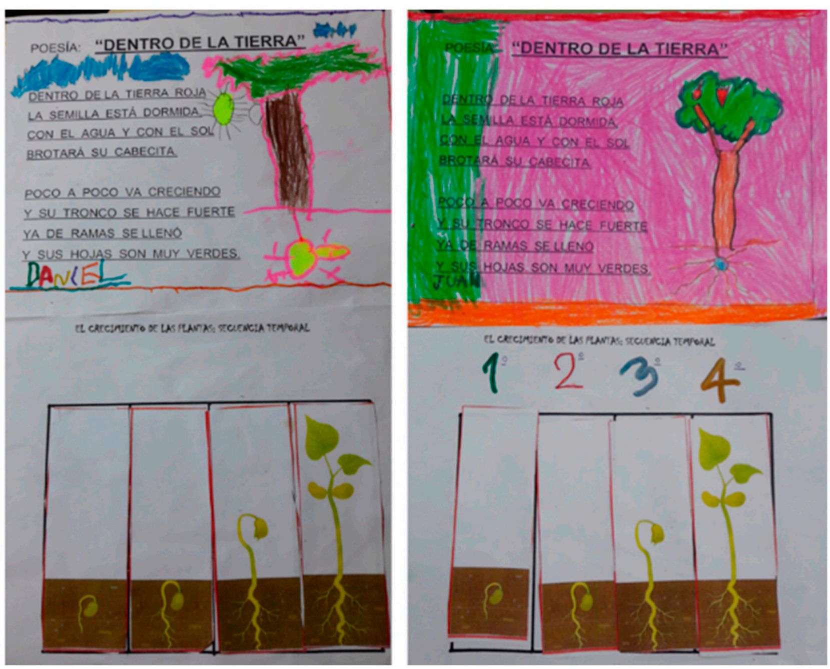

Figure 6. Poetry ("Inside the red earth, the seed is asleep; with the water and the sun, its little head will sprout. Little by little it grows, and its trunk becomes strong. It has already filled with branches, and its leaves are very green") and time sequence of the life cycle of a plant's growth.

The students showed surprise when they appreciated that between the seeds that they had planted themselves, simultaneously in the same container, there were disparate growths. Others, in addition, also expressed their confusion about the fact that other groups of students obtained different growths. These ranges in growth, which for scientists fall within normality, surprised these children for the first time, providing them with an interest in learning about science. On the other hand, we also identified interesting reflections on whether or not one's expectations were met with respect to expected growth. We consider that this variety of outcomes not initially expected by students is an important reason to justify the need for these records of information, even at these very young ages.

Table 5. Fragments of conversations between the teacher and the students on the results obtained in the work of the educational intervention.

Teacher	Student
Well, yours have grown. And many have come out. You've taken good care of them, haven't you?	Mine have grown, but less.
And what happened to yours? Do they all measure the same?	No
And yours? How much? Well, tell him to lend it to you	Mine have grown a lot! But if I don't have any ruler
Who has the tallest plants on this team?	Ángela

Finally, it could be observed that through familiarization activities with fruits, vegetables, and legumes, the students learned new scientific content and developed research skills. The children were able to recognize the diversity in fruits, vegetables, and legumes, the changes that take place in them during their life cycle, and how they interact with the environment that surrounds them. The teacher recognized the effectiveness of the activities in motivating the students to acquire knowledge about the environment, as well as in developing the ability to integrate content from other areas with meaning for the students, such as counting, reading, writing, and the arts. Therefore, it is considered necessary to continue with this type of proposal, reducing the use of decontextualized and meaningless files.

(d) Answering the questions included in the interviews.

In Table 6 we present some examples of the responses obtained in interviews with children from both the experimental and control groups after carrying out the activities. The interview was semi-structured in order to guide and promote the expression of their ideas.

Table 6. Answers obtained from semi-structured interviews *.

	Experimental Group	Control Group
Questions	**9 Girls, 8 Boys**	**7 Girls, 7 Boys**
Have you ever planted?	Yes (17)	Yes (7)/No (2)/I do not remember (5)
What have you planted?	Examples: Trees, plants, bulbs, all fruit and all vegetables, food, seeds, flowers, beans, oranges, pears, lemons, all kinds of things, broccoli, onions, tomatoes, black grapes, kidney beans	Examples: Watermelons, cherry tomato, mint, strawberry, flower, tomatoes, bananas, seed, tangerine, orange, apple, lemon, carrot, lettuce, beans, apple, pear, cucumbers
Where?	In the school garden (17), home (6)	At home, a family member's garden, after-school activity
Why do you think they are planted?	Eat (10), grow plants (6), nice garden (2), so that there are more trees (1)	To catch them and eat them (4), so that they grow up (2), I don't know (2), so that my grandfather can get good (1), for my grandparents (1), to grow plants (1), so that they do not break (1), so that they have sisters and are not alone (1), because it was the first time (1), to eat them in summer (1), to make the environment (1), to take them when they turn yellow and green (1)
Where do the fruits and vegetables we eat come from?	From the garden (10), from the trees (3), from the land (1), from the plants (1), I don't know (1)	We buy them in a supermarket (3), I don't know (2), of the plants (2), of the trees (2), of the leaves of the plants (1), they arrive in a car at the store (1), of the orchard (1), from a seed (1), a flower comes out of the seed, I have not seen it but I have told you (1)

Table 6. *Cont.*

	Experimental Group	Control Group
Questions	**9 Girls, 8 Boys**	**7 Girls, 7 Boys**
And did you like to eat it?	Yes (17) Examples: cucumber, broccoli, cauliflower, carrot, apple, watermelon, grapes, banana, orange, pear, tangerine, strawberry	Yes (14) Examples: apple, banana, watermelon, nuts, strawberry, tangerine, orange, carrot, tomato, grape, peach, salad, pear, persimmon, strawberry yogurt
Why do you think we have to eat fruit and vegetables?	To be healthy (6), to be strong (5), not to get sick (3), because I like it (2), to get older (1), so that our body is well (1), for desserts (1), to have vitamins (1), I don't know (1)	So that we are strong (5), because it is healthy (5), to get healthy (2), not to get sick (2), because we get big/grow (2), it is a fruit (1), it has nutrients that are good (1), to be well (1), not eat anything bad (1), because they are good for the stomach (1), because they are vegetables (1), if we do not eat vegetables we get fat (1), to eat (1), because they have vitamins but don't know what it is (1), because I am very hungry (1), it is healthier than bad things (1), so as not to get fat (1), healthy means that you have to eat it (1)
What do we plant for?	So that later we can eat them (16), so that it grows (4), so that there are many trees (1), for the fruit (1)	To later eat it them (6), I don't know (2), to have strength (1), to get thinner (1), to get bigger (1), to grow plants and sometimes come out with fruits (1), so that they are born because if not, the flowers would not live in spring (1)

* The value in parentheses corresponds to the number of children who gave this answer.

The affirmative or negative answers were not counted when the interviewer explained the answer to the question if any student did not answer. For example, if they did not answer "Why did we plant?" and the interviewer indicated the answer, the students tended to agree; however, the answer was not counted. On the other hand, some questions had more answers than students, when one of them mentioned more than one aspect.

As concluded from the interviews, knowledge is acquired from contexts other than school, such as the children's families. The children in our sample expressed ideas as a result of observation and interaction with the world around them. However, sometimes these ideas deviated from scientific ideas. The formative intervention through direct experience with fruits and vegetables led to the development of more scientific ideas about food competence in early childhood education.

The students from the experimental group, who worked in the school garden, tended to say that "we go to the garden, we pick up the food, and then we go home and eat it", a fact that may have contributed to promoting a greater association between garden care and the promotion of healthier eating. Some of them said that "each child plants their favorite fruit in the garden", which could help them become familiar with more fruits and know about the tastes of the rest of their classmates. In addition, they recognized that they eat fruits because "José Antonio (teacher) has given me a mandarin to take home and eat it". They also mentioned aspects such as "to plant you have to grow a seed" or "if you eat an orange that has already left the orchard and has a seed, it may be a seed", so they already have knowledge about the plant cycle, since they know about seeds. They recognized the importance of caring for the environment since "the garden remains beautiful and with beautiful trees and so when we want to go to the garden the more we go, the more trees there are. One day we find a plant in a bottle, but it was small, it had not yet been born. It was dry, nobody took care of it, we took it to class and José Antonio took care of it, so we poured water on it so that it would grow more and so on. When it grows we leave it in the garden". Other times, most students from the control group alluded to facts that they knew even if they had not observed them. For example, "a flower comes from the seed, I have not seen it but I have already told you" because these contents were also studied as part of the training program in this group. Furthermore, in the experimental group there was a slight improvement in the association between the plants of the school garden and the food, undoubtedly influenced by the experience of planting and caring for the plants at school. In the interviews, the majority indicated that the garden plants had been planted to feed us and, consequently, the majority related the fruits and vegetables they consumed with their origin in a garden. However, in the control group, the responses to these questions presented a greater variety, for example, the selection of "strawberry yogurt" as a fruit they like to eat, a reflection that this association is achieved to a lesser extent.

In both classes, healthy habits had started to develop, as all the interviewees answered that fruit and vegetables should be eaten. In relation to the term healthy, they did not know its exact meaning but they had ideas, such as that certain foods are healthy "because they are vegetables" or "because I like it", using concrete rules to classify them, such as the family they belong to or their own food preferences [25]. In some cases, they mentioned that "healthy food is rich food and it is for you to have more strength" or that fruits and vegetables have nutrients or vitamins, but that they did not know their meaning, or simply that they must eat them because they are fruits or vegetables. These results demonstrate that food classifications based on constituent nutrients are too abstract for these ages [35].

(e) Teacher self-assessment.

The teacher highlighted the possibility of achieving the objectives of observing nature and its characteristics from a "scientific" perspective in a very gratifying way for both the children and himself, since the children were free to choose the activities they performed. On the other hand, they experienced a lack of materials (a single seedbed for the whole class instead of one per group), space, time, and human resources. For future years, the teacher requested the amplification of the material assigned to each group, an increase in the area of the garden so that it could be used by more students, allowing more time for the activities to be able to conduct them in greater depth, and the use of a support teacher to carry out alternative activities with the students who are not in the garden at the time.

4. Discussion and Educational Implications

The problem of childhood obesity, which has been increasing in alarming proportions in recent years [69], must be attacked in a key setting, the school. Thus, personal experiences of students regarding the cultivation and care of plants (which they associate with food) might favor an increased preference for and intake of fruits and vegetables, which may reduce the risk of chronic disease development associated with diet [48]. In this way, this work has addressed some of the aspects that must be considered in the educational field from the first stage of school, such as early childhood education. We present an example of some activities necessary to promote familiarization with fruit and vegetables, along with the initial development of certain essential skills required for preschoolers to acquire food competence. Specifically, the following results should be highlighted:

- In accordance with our first objective of initiating early childhood education students in the learning of some basic scientific skills, we verified that the development of competence in food must be carried out throughout the school stage, so it is necessary to incorporate more activities that address other contents, such as the classification of foods, the observation of their characteristics, or taste-tasting activities. Due to the limited intervention that we carried out, we do not intend to generalize our results to the entire preschool population. However, we did see important differences between the schoolchildren who followed the designed activities and the control group of the same age and school. In this way, we consider that the students from the experimental group began to acquire the basic scientific competences related to plant foods (observing, measuring, and food competence).
- The identification of difficulties in the development of such competences, as we established in our second specific objective, needs special attention. According to the monitoring of the germination and growth of the plants in data tables, we were able to verify that this was a skill that required greater dedication from the teacher in order

to ascertain that the task was carried out and to resolve of the doubts that could be raised. Nevertheless, we consider that it is of great importance for the beginning, even if it is incipient, of systematic work in this area.

- As has been noted, it was possible to transfer to the usual classroom some of the basic tasks for the development of these skills. Thus, as a consequence, in relation to our third more specific objective regarding the care and cultivation of vegetables and legumes by schoolchildren, we consider it of great importance that educational centers have a school garden in which activities for preschoolers can be planned, allowing content related to obtaining healthy foods and the possibility of trying them, both at school and at home, to be addressed. In this way, the work in the school garden allowed preschoolers to relate plant food with living beings and their origin. In addition, the design and implementation of the sequence of activities from the competence framework allowed us to select content related to food relevant to children in early childhood education through a vocabulary that is understandable and appropriate to the child's cognitive stage. These activities, together with the promotion of collaboration between educational centers and families, promote the development of competence in nutrition in early childhood education. On the contrary, in the control group, some students had difficulties in establishing the origin of plant foods ("We buy them in a supermarket"), in accordance with results reported by other international studies [70], whereas this statement was not made by any of the students in the experimental group.
- Moreover, it is necessary to emphasize that the experience was a success for both the teacher and the students. Therefore, it has been proposed to extend the implementation to the rest of the early childhood classes in the next academic years.

Finally, it is worth mentioning current recommendations for influencing children's healthy behavior patterns, which suggest acting in various sectors. With regard to food, it is known that the commercial sector has a great influence on children, so it is essential to have adequate proposals to educate children in health-related areas. The design of useful interventions for children between 4 and 6 years of age, which aim to help parents and educators to positively influence the body weight of young children through adequate nutrition, requires further consideration and represents an area of fast-growing research. For future studies, children's reasoning about food should be explored in depth, especially their reasoning in regard to 'healthy' and 'unhealthy' groups [26] and how the concept of health is developed during the childhood years [25]. Thus, it is of great importance that educators consider the differences found in the conceptual understanding of health and nutrition in young children, making it necessary for teachers to base the curricula on the children's cognitive development levels. Moreover, people's eating patterns are determined by their exposure to certain actions, as well as their own personal choices. Knowledge, perceptions, and decisions to select a food can have a significant impact on interventions aimed at changing food intake and preferences. It is necessary to incorporate activities that allow students to know and become familiar with different types of fruits, vegetables, and legumes through direct manipulation. In this way, children begin the development of scientific competence through the teacher's guidance and the formulation of appropriate questions.

To summarize, in order to complete the development of food competence, an issue of great importance for our schoolchildren, multiple approaches that complement the work carried out in schools are required.

- Parents should be educated on the fundamentals of healthy eating and physical activity and be involved in school initiatives. Furthermore, schools must educate students on healthy eating and practical skills to achieve adequate nutrition, developing a program that reaches homes and incorporates peer teaching. Likewise, it is highly recommended that fresh fruits and vegetables are available daily, preferably for free.
- It is necessary to encourage daily physical activity, both inside and outside of school. In addition, politicians should promote initiatives that encourage programs to promote

employee and family health; establish physical activity facilities in the workplace; modify the built environment to encourage physical activity; and spread health messages [42].

- The medical community can also collaborate by promoting effective counselling for families, as well as developing resources to complement this, and governments must also implement more effective measures than the current self-regulatory systems, in order to counteract distorted advertising information offered by the media [71].

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education sciences

Article

Developing an Observation Tool to Measure Preschool Children's Problem-Solving Skills

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Abstract: In the Next Generation Science Standards (NGSS), problem-solving skills are part of science and engineering practices for K–12 students in the United States. Evaluating these skills for the youngest learners is difficult due to the lack of established measures. This paper reports on our process of developing an observation instrument to measure preschool children's learning and their application of problem-solving skills, namely, the steps of the engineering design process (EDP). The instrument, Engineering Preschool Children Observation Tool (EPCOT), was intended to evaluate the frequencies of problem-solving behaviors and use of EDP-related vocabulary by observing preschoolers engaged with the Seeds of STEM eight-unit curriculum in the classroom. In this paper, we describe the development process and revision of EPCOT, its current constructs, and present descriptive findings from using the tool in a pilot study with sixteen classrooms: eight intervention classrooms who received the entire curriculum, and eight comparison classrooms who received only the eighth unit of the curriculum (to enable comparison). We found that, out of 34 possible behaviors across the problem-solving process, children in all classrooms engaged in 31 unique problem-solving behaviors, suggesting that preschool children are indeed capable of meaningfully engaging in solving problems. We also observed a trend that children who were exposed to more of the curriculum (the intervention group) produced more novel vocabulary words than those in the comparison group, who tended to repeat vocabulary words. Since EPCOT was developed in alignment with state and national standards, we believe it has the potential to be used with other early childhood engineering/problem-solving curricula.

Keywords: STEM education; problem solving; early childhood; observation tool

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1. Introduction

Policymakers, educators, and researchers consider science, technology, engineering, and math (STEM) literacy and expertise to be critical human capital competencies for the 21st century. However, research points at persistent gaps in the United States with regard to access, opportunities, and performance in K–12 STEM education, where female students, racial minority students, and students from high poverty backgrounds lag behind their White male and Asian counterparts—a pattern demonstrated as early as kindergarten [1–3].

Despite promising evidence that introducing STEM/engineering ideas and practices during the early childhood years supports children's cognitive development and positive attitudes toward learning and inquiry [4–7], there is very little STEM instruction within pre-kindergarten classrooms [8,9]. In recent years, several published reports called for investment in early childhood STEM research, curricula, and high-quality professional development programs for teachers [10,11]. However, eight years after the release of the K–12 Next Generation Science Standards (NGSS), which includes engineering practices [12], there is still a great need for a research-based and standards-aligned STEM curriculum and assessment that enables early childhood teachers to engage their young learners in STEM experiences and evaluate the development of their problem-solving and analytical skills.

The wide range of abilities at the preschool age, especially with regard to language, makes it especially challenging to assess preschool children's problem-solving skills in an authentic setting. Our review of the literature reveals several authentic assessments focusing on math and science learning and engineering "habits of mind" [13], but does not reveal any validated measures for evaluating preschool children's problem-solving abilities, specifically the application of the steps of the engineering design process (EDP) when solving problems.

This paper reports on our team's process of developing an observation instrument to measure preschool children's learning and application of the EDP steps. The instrument, which we call the Engineering Preschool Children Observation Tool (EPCOT), was intended to evaluate the frequencies of problem-solving behaviors and use of EDP-related vocabulary by observing classrooms where a federally funded, full-year STEM curriculum was implemented as part of a 16-classroom pilot study [14]. Designed to evaluate problem-solving skills as identified by the NGSS [12] and the Commonwealth of Massachusetts [15], EPCOT has the potential to be used with other early childhood engineering/problem-solving curricula.

1.1. Problem Solving in Early Childhood

Developmental researchers have long believed that children are natural tinkerers [16] who use their conceptual knowledge and reasoning skills, as well as social information, to solve problems. To succeed in solving problems, children need to encode the problem accurately, which involves identifying important aspects of the problem and building a mental representation of the problem. This is often challenging for young children [17,18]. Indeed, early accounts on children's cognitive development, most notably Piaget's, indicated that young children cannot engage in problem-solving processes, such as scientific reasoning [19]. However, more contemporary research has shown that with the right support, such as when problems are simplified, children can succeed in solving problems. Even 3-year-olds can form complex mental models [16], indicating their capacity to mentally represent problems.

Differences in children's problem-solving abilities can often be explained not by cognitive-processing abilities that emerge only as they get older, but by considering the particulars of the situation: children's success in solving problems is greatly influenced by the different ways and contexts in which problems can appear [20]. For example, infants as young as 12 months can imitate an adult solving a modified balance-scale problem [21], and even 2-year-olds can solve the balance-scale problem when it is simplified [22]. Later research showed that when provided with opportunities to practice in a non-traditional way, older children are less likely to misconceive a problem involving a commonly misunderstood concept such as equivalence in math equations [23]. Children also innovate after *both* successes and failures—they can generate new strategies for a familiar problem that they have previously solved using an older strategy [24].

These findings illustrate a common theme that has emerged in the cognitive developmental literature: that children are *flexible* problem solvers. Instead of linearly going through strategies that increase in sophistication as they get older, children show cognitive flexibility by entertaining different ways of representing and solving a problem at a given time [25,26]. Children's tendency to entertain multiple strategies and deploy them in different ways, depending on the context, suggests that children have the capacity to brainstorm solutions. These findings suggest that we can leverage children's conceptual understanding and problem-solving potential to teach them a systematic approach to problem solving: the engineering design process (EDP).

The National Research Council (NRC) in the United States defines engineering as "engagement in a systematic practice of design to achieve solutions to particular human problems" [27] (p. 11). The Council's Framework for K–12 Science Education states that children are natural engineers, who build castles, dollhouses, and hamster enclosures using a variety of tools and materials. This natural interest and ability can be enhanced by asking them to test and redesign their structures and by paying attention to challenges in their design and construction efforts. The *NGSS* [12], developed based on the NRC's Framework, emphasizes engineering practices starting as early as kindergarten as part of the new set of science standards. According to the *NGSS* developers, engineering is a context-based subject with real-life applications, which makes it applicable to a diverse group of students and therefore serves as a promising opportunity for deepening scientific knowledge [12].

Since the development of the *NGSS* and its emphasis on science and engineering practices, there is a growing need to engage students in problem-solving activities. In recent years, several STEM and engineering curricula were developed specifically for preschool settings [13,28–30]. Raven et al. (2018) designed a series of science and engineering activities to introduce the EDP to preschool-age children. Within each activity, three main practices were emphasized: Asking Questions (for science)/Defining Problems (for engineering), Planning and Carrying Out Investigations, and Constructing Explanations (for science)/Designing Solutions (for engineering). The authors claimed that, even in preschool, children can ask questions, design solutions, and improve their designs like engineers do. Lippard et al. (2018) observed nine preschool classrooms and found that in all but one classroom, children exhibited engineering "habits of mind," such as systems thinking, collaboration, communication, ethical consideration, and optimism [13]. In a study conducted by Lottero-Perdue et al. (2015), in which preschool and kindergarten children engaged in an engineering and design lesson, the teachers reported that students were deeply engaged, enthusiastic, and had a desire to problem-solve [31]. Other observed outcomes for engineering activities include critical thinking, problem solving, collaboration, persistence, and other adaptive domain-general learning skills [32]. The increase in early childhood engineering and problem-solving activities also requires the development of age-appropriate authentic measures in order to determine the impact of the curriculum on children's learning outcomes and help improve instruction.

1.2. Measuring Early Childhood Problem-Solving Skills

Similar to effective instruction that follows evidence-based learning trajectories, an effective assessment should measure attainment of the learning goal (i.e., mastery of content or skill), the developmental progression toward that goal (i.e., levels of cognitive processing needed to master the content or skill), and performance on the instructional activities (i.e., tasks and other problem-solving experiences) designed to support the development of these cognitive skills [33]. The assessment should also address whether the curriculum has had positive, long-term outcomes, such as continued and accurate use of terms learned (sustainability), application of knowledge gained (persistence), and innovation that continues outside of the curriculum (diffusion) [33]. An authentic classroom assessment is one that engages the student's intrinsic interests and cognitive capacities, and is intended to measure transferrable skills and abilities [34]. In the case of preschool children's competencies, observing them in their natural playing and learning environment is crucial for authenticity [34–36]. Curriculum-embedded assessments can be administered in a variety of formats, such as via observations, direct testing, and interviews [36]. Hence, the measurement of young children's knowledge and application of problem-solving vocabulary and skills should focus on authentic observations as children engage with meaningful problems in a variety of classroom tasks.

Methods to evaluate children's problem-solving skills and knowledge tend to fall into several categories: (1) analysis of children's discourse during free play (i.e., [37,38]); (2) observations of children at play [39]; curriculum-specific observation protocols for researchers and teachers (i.e., [40]); (3) evaluation of engineering habits of mind ([13]); and (4) assessment of children's science and engineering knowledge through pictorial measures [41]. Of these categories, only the last one, which doesn't measure problem-solving skills, has been validated.

Despite the development of standards-aligned engineering and problem-solving curricula and classroom experiences, there is a lack of a valid measure to be used by teachers and researchers [41,42]. Methods for assessing science and engineering knowledge and skills are critical for both researchers and teachers who are interested in children's learning and ways to improve science and engineering teaching efficacy [33,42]. The lack of established measures has led researchers to develop ad hoc tools for their projects, making it difficult to build upon previous work and replicate studies [43]. Hence, there is a need for an observation protocol that is aligned with national standards and that could be used with multiple curricula to evaluate young children's engineering/problem-solving skills.

1.3. The Current Project: Overview

Seeds of STEM was funded by the U.S. Department of Education [14] as a development project, with the goal of developing a new problem-solving curriculum for preschool classrooms serving 3- to 5-year-olds. In line with the grant structure, the developed curriculum was piloted in preschool classrooms to demonstrate feasibility and fidelity of implementation as well as potential for a larger study. The project was divided into two major parts: curriculum development and pilot study.

Curriculum Development. The development of the curriculum was conducted in partnership with Head Start, a federally funded early childhood education program developed by the United States Department of Health and Human Services, serving newborns to 5-year-old children from low-income families. Our partner Head Start program was from a large urban area serving close to 700 children in 35 classrooms. A team of six developer-teachers and twenty tester-teachers collaborated with the researchers to develop and test the multiple iterations of the curriculum's eight units over the course of two years (see [44,45] for a detailed description of the participatory-design curriculum development process).

Pilot Study. The pilot study was designed as an underpowered randomized control trial (RCT) in 16 mixed-age classrooms serving children 3–5 years old. These classrooms were part of a different Head Start program, which did not take part in the curriculum development process, and included classrooms in urban and rural settings. Forty teachers took part in the pilot study (twenty-one teachers in eight intervention classrooms, and nineteen teachers in eight comparison classrooms). Thirty-eight teachers identified as females, and 20% of the teachers identify as a minority (non-white). The student population included 238 3- to 5-year-olds (68% identified by their parents as a minority/non-white), with 130 children in the intervention classrooms and 138 in the comparison classrooms. The pilot study lasted one school year, followed by 20 months of data coding and analysis. Classrooms were randomly assigned to intervention and comparison groups (eight classrooms in each condition), matched for teacher characteristics based on an opening survey. Twenty one intervention teachers received 10 h of training prior to and during the implementation of Units 1–7 of Seeds of STEM, as well as classroom visits by the researchers. Nineteen comparison group teachers were asked to teach their current science/STEM curriculum, and did not receive any training or support. All 40 teachers were provided with Unit 8 of Seeds of STEM (the topic was light and shadow), and were asked to follow the curriculum and teach Unit 8 over the course of two weeks. See Figure 1 for an illustration of the study design. Teachers were offered the option of videotaping their own lessons or having a research assistant help with videotaping the Unit 8 lessons. Only children whose parents signed a consent form were included in the videos. This paper describes the lessons learned from the research team's development of an observation tool to evaluate children's problem-solving behaviors and vocabulary. While the development of the observation tool was not among the original goals of the study, it is our hope that other researchers would benefit from the description of the development process, and would be able to include and further validate the tool in future studies.

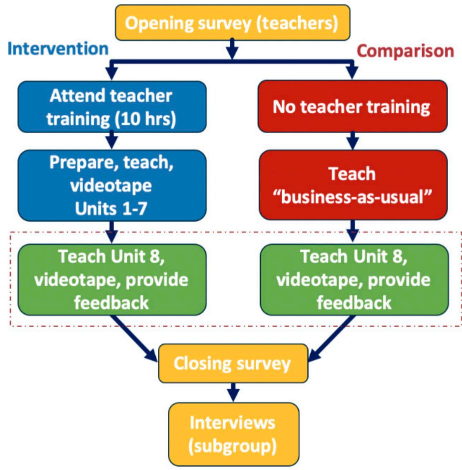

Figure 1. Pilot study design.

1.4. The Development of the Engineering Preschool Children Observation Tool (EPCOT)

EPCOT was developed to measure preschool children's problem-solving skills and vocabulary while engaged in Seeds of STEM activities in the classroom. The list of outcomes, for both the curriculum and observation measures, was created based on established standards and frameworks: the Engineering and Scientific Practices in the Massachusetts Science Technology/Engineering Framework for Pre-K (2014; 2019), the NRC Framework [27], and the Head Start Framework [46].

1.4.1. EPCOT Version 1

Based on the established standards and frameworks [27,46], the research team defined eight observable behaviors that are employed when solving a problem. For each one of the behaviors, the research team defined several levels based on increasing cognitive complexity (see Table 1). For example, for the first observable behavior of *describing/recognizing information*, the first, most basic component will be marked when a student repeats a statement about the scientific phenomenon, and the most sophisticated component will be marked when the student offers an example about the phenomenon from their own lives.

Table 1. EPCOT (v.1) with 8 actions and 33 observable behaviors (Levels of cognitive complexity).

1. Describing/recognizing information: The extent to which children can recognize the scientific phenomenon that underlies the problem.	Component 1: Repeat statement about scientific phenomenon. Component 2: Describe materials shared by the teacher (book, chart, model). Component 3: Offer observation or example from their own lives.
2. **Identifying the problem**: The extent to which children can articulate a problem and its implications.	Component 0: Repeat the problem after the teacher or another child states it. Component 1: Recognize and articulate the problem. Component 2: Explain why it is a problem.
3. **Obtaining information/asking questions**: The extent to which children ask questions about the scientific phenomenon, or about trying to understand the problem.	Component 1: Ask clarifying question (What is/Where is?). Component 2: Ask exploration question (Why does/How does?). Component 3: Independently explores (touches, plays, examines) lesson materials. Component 4: Prompted (by teacher) to explore materials.

Table 1. *Cont.*

4. **Brainstorming**: The extent to which children can draw on self- and others' knowledge and observations to come up with multiple solutions.	Component 0: Repeat a solution stated by the teacher or another child to a problem. Component 1: State a solution to a problem. Component 2: Predict outcomes and difficulties: advantages or disadvantages of a solution. Component 3: Classify solutions as testable versus non-testable. Component 4: Revising an initial idea/solution.
5. **Solution planning**: The extent to which children can develop a plan for the design of the solution using simple materials/equipment and investigate materials as needed.	Component 1: Choose/draw/describe a solution. Component 2: Discuss/explore/state what materials are needed/available. Component 3: Describe steps of carrying out solution. Component 4: Predict outcomes and difficulties: advantages or disadvantages of a solution. Component 5: Revise solution plan.
6. **Solution creating and testing**: The extent to which children can work with others to select and use materials to build the solution, implement the design, and gather data on the effectiveness of the solution.	Component 1: Create a model of solution. Component 2: Carry out a solution. Component 3: Identify an effective aspect of the solution (criteria and constraints). Component 4: Identify a limitation of the solution. Component 5: Revise the solution.
7. **Sharing findings**: The extent to which children can communicate the entire problem-solving and design process, articulate findings, and state conclusions to peers and teachers.	Component 0: Restate problem. Component 1: Present solution. Component 2: Explain a choice (material, final solution). Component 3: Describes steps of problem-solving process (idea, plan, solution, test results). Component 4: Discuss effectiveness and limitations of the solution.
8. **Using the Engineering Design Process**: The extent to which children can use the engineering wheel to communicate and elaborate on the problem-solving process.	Component 1: References/recognizes the current stage of the engineering design process. Component 2: Describes past activities or future steps in the engineering design process. Component 3: Spontaneously explores the wheel to guide problem solving.

In addition to these dimensions of action, the EPCOT was also designed to capture indicators of problem-solving vocabulary acquisition, in terms of the frequency of children repeating the words (e.g., *brainstorm*, *design*, *revise*), saying them when prompted (cued vocabulary production), and spontaneously producing them appropriately (novel vocabulary production). A team of trained blind coders who were unfamiliar with the Seeds of STEM curriculum tested the first version of EPCOT by observing classroom videos and scoring the behaviors they observed. The team encountered significant challenges in defining non-verbal gestures, needing to clarify each behavior to reduce code-misinterpretation, and struggling to differentiate curricular and general classroom activities. As a result, coders were not able to reach consensus and thereby meet the expected reliability (70%) on this first version of the EPCOT.

1.4.2. EPCOT Version 2

To address the challenges in coding encountered when using version 1 of the tool, the research team engaged in a process of creating "master-coded" videos that reflected the research team's goals for the observation tool (as recommended by the project's expert psychometrician). During that process, the research team observed dozens of classroom videos, discussed each observed behavior, and revised the EPCOT wording to reflect the agreement among the team and reduce ambiguity. As a result of this elaborated process, EPCOT was revised and a second version was created (see Table 2). In addition, a detailed training guide was developed. The revised EPCOT includes only five main actions, but each one consists of multiple observable behaviors to capture variations and nuances of each action. Out of the five actions, three follow the steps of the EDP (Actions 2–4), one focuses on connections to the scientific phenomenon and to the desirable skills of asking questions (Action 1), while the last action (Action 5) focuses on behaviors that demonstrate recognition and understanding of the problem-solving process itself. During the video observations, the research team was challenged by cases in which the children referenced the scientific phenomenon as they were engaged in different steps of the problem-solving process. To distinguish these behaviors from the general Action 1, we added special codes to Actions 2–4, namely 2.1, 3.1, and 4.1.

Table 2. EPCOT (v.2) with 5 actions and 33 observable behaviors.

Action/Category	Code	Behavior Description
1. Unpacking the Scientific Phenomenon or Process	1a	Repeat statement about scientific phenomenon.
	1b	Describe/reference/acknowledge materials/activities shared by the teacher related to a scientific phenomenon.
	1c	Offer an observation or example about a scientific phenomenon from experiences outside of the current activity.
	1e	Ask a clarifying question (What is/Where is?).
	1f	Ask an exploration question (Why does/How does?).
2. Identifying & Researching a Problem	2.1	Make a connection between the problem and any scientific phenomenon.
	2a	Repeat the problem soon after the teacher or another child states it.
	2b	Recognize/identify a problem (for the first time/analyzing a context to voice the problem/out of a situation presented to them).
	2c	Articulate/share/present a problem.
	2d	Explain (on their own) why it is a problem.
	2e	Explore materials/photos in order to understand the problem/solution.
3. Brainstorming-Planning-Choosing Solutions	3.1	Make a connection between the plan/proposed solution and any scientific phenomenon.
	3a	Repeat a solution stated by the teacher or another child to a problem.
	3b	Propose/state a solution to a problem.
	3c	Draw/explain/share a solution plan/idea.
	3d	Predict outcomes and difficulties: advantages or disadvantages of a solution (with or without teacher assistance).
	3e	Classify solutions as testable versus non-testable.
	3f	Revise an initial idea or plan.
4. Creating-Testing-Revising Solutions	4.1	Make a connection between the solution and any scientific phenomenon.
	4a	Discuss/explore/state what materials are needed/available while building or testing.
	4b	Create a model of the solution.
	4c	Discuss steps of building/testing a solution (during building/testing phase).
	4d	Carry out/test a solution.
	4e	Identify an effective aspect of the solution (criteria and constraints).
	4f	Identify/discuss limitations of the solution (after testing).
	4g	Revise/propose revisions (to) the solution/model (not plan or idea).
	4h	Present/state/explain the built solution to others (including choices made in creating/revising the solution).

Table 2. *Cont.*

Action/Category	Code	Behavior Description
5. The Problem-Solving Process	5a	Repeat the name of the current design process stage as stated by the teacher or another child.
	5b	Recognize the current stage of the engineering design process.
	5c	State (on their own or cued by teacher) past or future activities/steps in the engineering design process (regardless of accuracy), or name/recognize the process itself without describing the steps.
	5d	Spontaneously conduct the next step in the design process.
	5e	Describe the entire process (including all the steps from problem to solution).
	5f	Spontaneously explore/reference the wheel/process to guide problem solving.
	5g	Explain/show understanding of the purpose of one or more of the steps (for example: why do engineers plan?).

2. Materials and Methods

The second version of EPCOT was used to assess the level of problem-solving behaviors and vocabulary as exhibited by children in 16 Head Start classrooms (8 intervention, 8 comparison). These classrooms did not take part in the curriculum development process, and the teachers were not familiar with the curriculum. Teachers in the intervention group taught all 8 units of the curriculum and received professional development training. Teachers in the comparison group followed a "business-as-usual" protocol regarding the teaching of science. Both groups taught the last unit of the curriculum (Unit 8, Light and Shadow) as an assessment, and were asked to videotape all their classroom activities associated with the curriculum (conducted over 2 weeks in whole-class and small-group settings). The first week introduced the scientific concepts of light and shadow through stories, exploration, and experimentation. The second week focused on solving a problem related to the scientific concepts. Specifically, Problem Panda (the curriculum's main character) wants to play outside, but it is too hot and bright. The children were asked to create a solution to Panda's problem, based on concepts related to light and shadow. Only videos from the second (engineering) week were used for the analysis. Table 3, below, illustrates the different activities during the Unit 8 engineering week.

Table 3. Summary of Seeds of STEM weekly activities during "engineering week".

	Monday	Tuesday	Wednesday	Thursday	Friday
Large Group (the whole class)	6.1 Panda has a problem!	7.1 Setting criteria and brainstorming solutions.	8.1 Sharing plans, voting on class solutions.	9.1 Sharing and providing feedback on solutions.	10.1 Problem solved! Sharing with a special guest.
Small Group (3–5 children with the teacher)	6.2 Research the problem: how does it feel to play in the sun?	7.2 Planning solutions.	8.2 Creating and testing solutions.	9.2 Improving solutions based on feedback.	10.2 Creating a poster with pictures from the week.

2.1. Video Sampling

An algorithm was developed for randomly selecting videos from every classroom. The goal was to select a total of 6 classroom videos (3 videos of small group activities, 3 videos of whole class activities) out of 10 videos per class, in a way that all curriculum activities (from 6.1 to 10.2) are represented. In addition, the algorithm selected videos so that the total observable time was similar across all classrooms. The observable time of ~67 min was selected, based on the classroom with the least video recording time. This process was done to ensure equal observation time for all classrooms (In addition to standardizing videos prior to coding, we conducted robustness analyses in our main findings using linear regression to observe the association between behaviors and groups, controlling for time. These findings produced similar results to our main analyses and are available upon request). Prior to the selection, videos were trimmed for non-curricular activities, so the observation was mostly on the activities. Videos shorter than 3 min were excluded from coding.

2.2. Coder Training

Blind coders were trained using the master-coded videos. A detailed scoring guide was shared with the coders, and the document was updated during the training sessions. Coder questions about specific situations were answered by the research team after reviewing the video and agreeing on the next steps. The goal was to establish a reliability of 70% with the master codes and among coders. Two coders met the requirement and classroom videos were divided among them with a 25% overlap. Coder disagreements were reviewed and discussed by the coders and the research team.

2.3. Coding Software

The coding of problem-solving behaviors and vocabulary was done with Behavioral Observation Research Interactive Software (BORIS), a free and open-source video-coding software. BORIS's main features include adaptability to code entry, a timestamp for each code, an easy export function, user-friendliness, and privacy of video subjects. The use of the software allowed for numbering and coding individual students—a valuable tool when coding groups of participants—enabling the coder to track the total number of participating students out of the entire class.

2.4. Coding for Behaviors and Vocabulary

As coders watched the videos, they coded for a specific behavior and marked the child(ren) who exhibited that behavior (see Table 2 for behaviors and categories). This allowed for a summary of the percentage participation of each classroom. In addition, the coders coded for expressive language of one of the designated problem-solving vocabulary words: *engineering design process/engineering wheel*, *problem*, *solve/solving*, *solution*, *engineer*, *brainstorm/think*, *idea*, *choose*, *plan*, *design*, *create/build*, *revise*, *improve/make better*, and *share*. On the coding software, the coders noted whether the vocabulary words were produced spontaneously by the children or repeated after the teacher or another child mentioned the word.

3. Results

3.1. Students' Problem-Solving Skills and Vocabulary

Trained and reliable blind coders scored six randomly selected videos for each classroom (three small-group activities, three whole-class activities). Coding output (through BORIS) included frequency of problem-solving behaviors, frequency of expressed vocabulary words, and proportion of students exhibiting the behaviors (out of total students in the video). In total, the findings are based on 90 coded video clips across all 16 classrooms (out of the expected 96; the loss was due to technical issues with the videos or missing coded files). Among these videos, there was a representation of all 10 curricular activities that were implemented during the engineering/problem-solving week (as depicted in Table 3).

Overall, 1696 behaviors were coded, of which 19% were coded under category 1 (unpacking the scientific phenomenon or process), 11% under category 2 (identifying and researching the problem), 26% under category 3 (brainstorming-planning-choosing solutions), 34% under category 4 (creating-testing-revising solutions), and 9% under category 5 (the problem-solving process), as depicted in Figure 2.

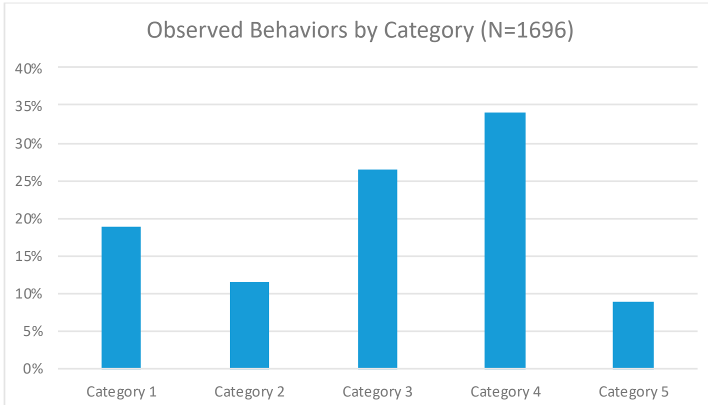

Figure 2. Observed behaviors by coding category.

The six most frequently observed behaviors account for 53% of all observed behaviors. These behaviors include 1b (Describe/reference/acknowledge materials/activities shared by the teacher related to a scientific phenomenon), for example, when a child points out a shadow in the picture made by the sun and the trees; 3b (Propose/state a solution to a problem). For example, one of the children proposed to make a "house out of leaves so he can't burn"; 3c (Draw/explain/share a solution plan/idea), where a child was observed explaining how an umbrella works during the planning process; 4a (Discuss/explore/state what materials are needed/available while building or testing), for example, when a child explained "you would need glue to stick the cups together"; 4g (Revise/propose revisions (to) the solution/model), for example, when a child holds up a piece of cardboard and says "this can be the roof"; and 5c (State past or future activities/steps in the engineering design process (regardless of accuracy) or name/recognize the process itself without describing the steps), for example, saying that, at the beginning, we need to find out "what the problem is."

Interestingly, three behaviors were not observed at all in all 90 videos: category 3e (Classify solutions as testable versus non-testable), 5e (Describe the entire process, including all the steps from problem to solution), and 5f (Spontaneously explore/reference the EDP poster to guide problem solving). Figure 3, below, shows the distribution of observed behaviors.

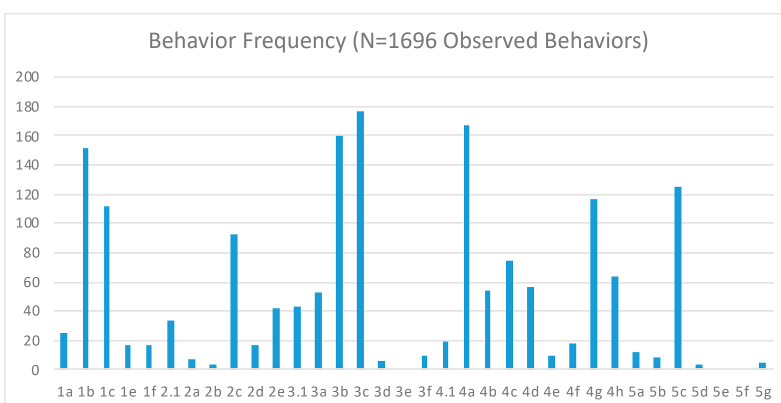

Figure 3. Behavior frequency.

We analyzed differences in observed child behaviors across specific areas of the EPCOT, small- and whole-class settings, and intervention and comparison groups. We hypothesized that some behaviors would be more likely to occur than others, for example, that students repeat vocabulary words rather than propose a solution or revise initial plans. Further, some behaviors would be easier for students in small groups versus a whole class, for example, having more opportunities to engage in testing solutions (category 4). Additionally, we expected to see more higher-level behaviors (category 5) in the intervention group than in the comparison group, since teachers and students had more practice and engagement in the intervention group and it would be easier to demonstrate higher-order processing. We present the results of our hypotheses testing here, acknowledging, however, that this is an exploratory study focused on the development of EPCOT as a rubric. The study was therefore conducted in a smaller number of classrooms, focusing resources on the use of curriculum and the EPCOT rubric in each classroom. We do not necessarily have the power required to detect statistically significant differences across groups. Still, the observation of trends is important and can set a baseline for expected results in larger settings.

We found that behaviors were evenly divided between small-group and whole-class activities (see Figure 4) in category 2 (6% and 6%), category 3 (14% and 13%), and category 5 (4% and 5%). However, more category 1 behaviors occurred during whole-class activities (12% vs. 7%), and significantly more category 4 behaviors occurred during small-group activities (31% vs. 3%). These findings were expected, as the children were revisiting science concepts discussed in the previous week during the first whole-class circle of the week, and engaged in creating their solutions in small groups. Behaviors of categories 2, 3, and 5 were discussed throughout the week in both small-group and whole-class settings.

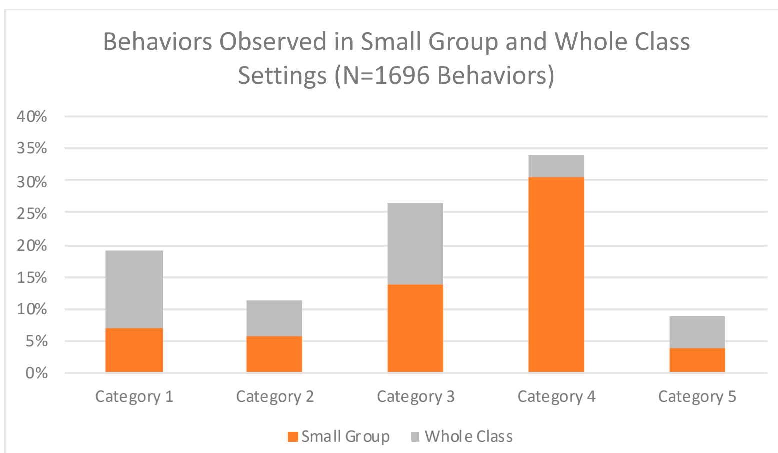

Figure 4. Behaviors observed in small-group and whole-class settings.

An analysis of children's vocabulary captured a total of 436 vocabulary words related to problem solving, of which 312 words were produced spontaneously by the children, and 124 words were repeated after they were first mentioned by the teacher or by another child. The majority of the captured vocabulary words (73%) fell into five categories: *brainstorm/think* (22%), *problem* (15%), *idea* (14%), *plan* (12%), and *create* (10%). The rest of captured vocabulary words (27%) included the words: *solution*, *share*, *solve*, *design*, *engineer*, *build*, *test/testing*, *improve/improving*, *creation*, and *choose*. Figure 5 shows the distribution of vocabulary frequencies.

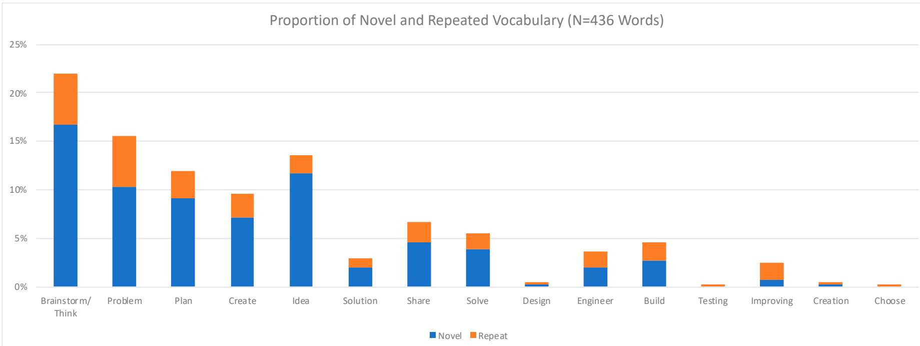

Figure 5. Proportion of novel and repeated vocabulary words.

3.2. Differences across Groups

No significant difference was detected between the intervention and comparison groups in terms of frequency of behaviors (Figure 6) and problem-solving vocabulary (such as *problem*, *solution*, *brainstorming*, *and planning*): 53% of behaviors were observed in intervention classrooms, and 47% of behaviors were observed in comparison classrooms. Although we expected to see differences in student behavior in the intervention and comparison groups, these differences were not statistically significant. This may be due to the lack of statistical power (sample size) to detect effects. Another unexpected finding was related to category 5 behaviors that address the problem-solving process and its steps, where observed behaviors were evenly divided between the groups.

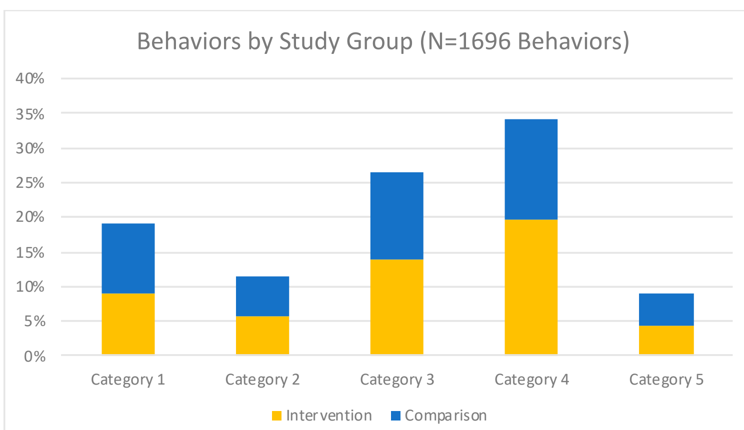

Figure 6. Behaviors by study group.

In order to analyze differences between groups, we tested (using a one-tailed, two-sample *t*-test) the difference in small-group and whole-class activities, and intervention and comparison group activities, across the five coding categories. As shown in Table 4, there were statistically significant differences between small-group and whole-class activities in category 4. As expected, creating-testing-revising solutions (category 4) occurred more often in small groups. The differences in findings across the whole-class and small-group settings may suggest that some activities are better geared toward particular classroom arrangements.

Table 4. Behavior and vocabulary frequencies by coding category.

		Overall	Small Group	Whole Class	Intervention	Comparison
1. Unpacking the Scientific Phenomenon or Process	*Mean*	10.99	8.2	14.2	11.2	11.0
	SD	10.90	10.1	12.7	12.1	11.7
2. Identifying-Researching a Problem	*Mean*	6.40	6.6	6.4	6.9	6.2
	SD	3.44	4.1	3.2	3.4	3.9
3. Brainstorming-Planning-Choosing Solutions	*Mean*	14.92	15.9	14.5	15.9	14.5
	SD	12.53	14.2	12.9	13.4	13.8
4. Creating-Testing-Revising Solutions	*Mean*	19.28	34.5 **	4.3 **	24.1	15.8
	SD	23.40	26.4	4.6	25.7	23.2
5. The Problem-Solving Process	*Mean*	5.00	4.4	5.3	4.6	5.1
	SD	6.24	6.3	7.3	5.8	7.6
Vocabulary (Novel)—Problem Solving	*Mean*	9.28	7.8	10.4	9.4	8.6
	SD	8.18	7.6	10.0	7.9	9.7

Note: Overall observations $N = 31$, Small group $N = 16$, Large group $N = 15$, Intervention $N = 16$, Comparison $N = 15$; * p-value < 0.005, ** p-value < 0.001.

Similarly, a vocabulary group analysis did not reveal significant differences between the intervention and comparison groups in terms of overall frequencies. A total of 215 words were captured in videos from intervention classrooms, and 221 words were captured in videos from comparison classrooms (see Figure 7).

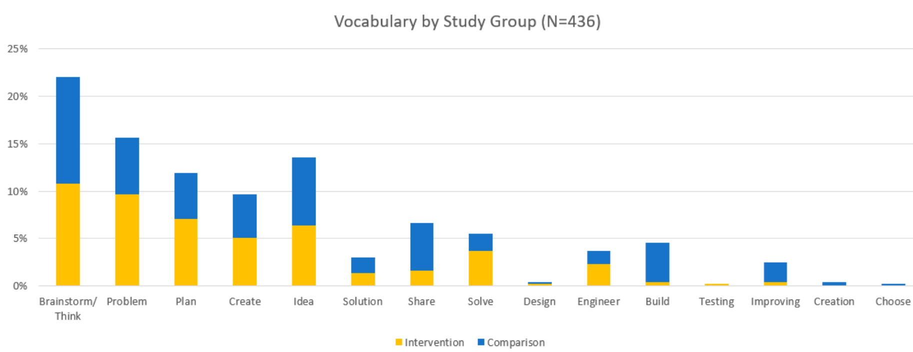

Figure 7. Proportion of vocabulary words by study group.

An additional analysis revealed an interesting trend such that children in the intervention group produced a slightly larger percentage of novel than repeated words (75% novel vs. 25% repeated) compared to those in the comparison group (68% novel vs. 32% repeated; see Figures 8 and 9).

To further analyze the vocabulary data, we defined a threshold of at least 50% more vocabulary words than the other group for any difference to be meaningful. Based on this criterion, the intervention group had substantially more novel vocabulary words under the categories *problem*, *plan*, *solution*, *design*, and *engineer*, and more repeated vocabulary words under the categories *think*, *problem*, *solve*, and *testing*, compared to the comparison group (see Table 5). This pattern may suggest that children who were exposed to more of the curriculum (the intervention group) produced more novel vocabulary words than the comparison group, who were exposed to just one unit of the curriculum. The children in the comparison group seemed to be more engaged in repeating vocabulary than the intervention group. There were also categories where the two groups were comparable:

brainstorm, *think* (novel), *plan* (repeat), *create* (novel), *idea* (novel), *solve* (novel), *engineer* (repeat), *testing* (novel), and *choose* (novel). There were no vocabulary words in either group for *testing* or *choose*.

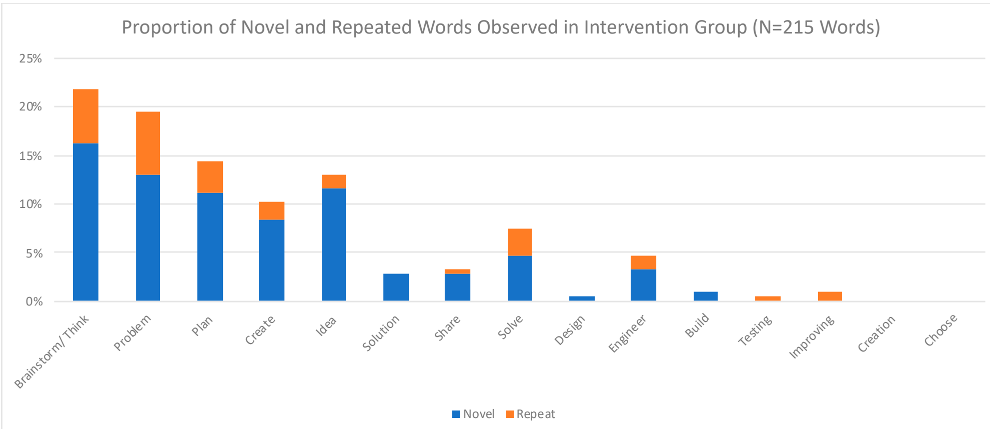

Figure 8. Proportion of novel and repeated words in the intervention group.

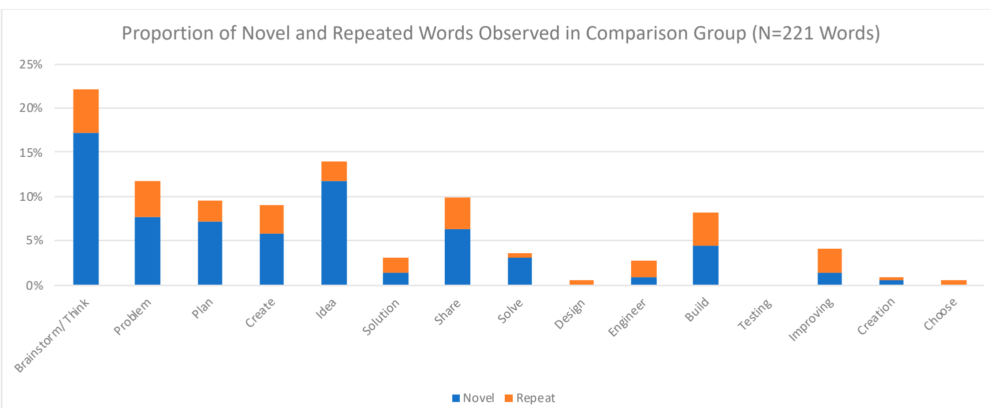

Figure 9. Proportion of novel and repeated words in the comparison group.

Table 5. Differences in vocabulary use across groups.

More Vocabulary in Intervention Group (At Least 50% More Vocabulary Words)		More Vocabulary in Comparison Group (At Least 50% More Vocabulary Words)	
Novel	**Repeat**	**Novel**	**Repeat**
Problem Plan Solution Design Engineer	Problem Solve Testing	Share Build Improve Creation	Create Idea Solution Share Design Build Improve Creation Choose

Thus far, our findings suggest that the Seeds of STEM curriculum engaged children in all steps of the EDP, and elicited vocabularies and behaviors associated with the process. Although we expected to see differences in student behavior in the intervention and comparison groups, these differences were not statistically significant, which may be due to the lack of statistical power (sample size) to detect effects. However, the intervention group showed, on average, 24.1 behaviors in category 4, compared to 15.8 behaviors in the comparison group (see Table 5). These differences are substantively meaningful and are trending in the expected direction; however, a lack of precision due to the small sample size obscures our ability to detect statistical differences (In addition to using a *t*-test to assess differences between groups, we also used hierarchical linear modeling to test differences across groups while accounting for clustering of teachers and students in classrooms. Similar to the findings we present here, we found some trends, but nothing statistically significant).

4. Discussion

EPCOT was developed to observe preschool children's problem-solving behaviors and vocabularies in classrooms that tested the Seeds of STEM curriculum. A total of 1696 behaviors were observed in videos taken from 16 preschool classrooms. Out of 34 possible behaviors across the problem-solving process, the children in these classrooms engaged in 31 unique problem-solving behaviors, implying that preschool children are, indeed, capable of meaningfully engaging in solving problems.

The process of establishing EPCOT was long and required dozens of hours of video observations, discussions of ambiguous situations, and resolving disagreements between coders and the research team. However, the process resulted in a detailed training guide that enabled the training of reliable coders.

The high correlations between behavior category and curricular activities were expected, as both EPCOT and the Seeds of STEM activities followed the problem-solving process from identifying problems to sharing the revised solutions. However, we have observed behaviors from all categories in the different steps. For example, during a video clip of children planning the solution to Panda's problem, the children were observed talking about the problem (e.g., "it's getting too hot and Panda needs some shade"—category 2), discussing criteria and constraints (e.g., "solution needs to be able to make Panda cool" and "solution needs to be kind of large for Panda"—category 2), planning the solution and connecting the solution to a scientific phenomenon (e.g., "he planned a large tower, and it will block the sun"—category 3), stating the next step in the problem-solving process (e.g., "we need to create the solution"—category 5), engaging in building their solution (category 4), and explaining their solution (e.g., "I will make a tunnel for Problem Panda"—category 4). Other observations include children discussing the problem, sharing and testing their solutions, and accepting suggestions from other children about improving their solutions. In other words, the children demonstrated that the process of solving problems is not linear, but requires repetitions and connections to the different steps throughout the process [25,26].

To our surprise, no significant differences were detected between the intervention and comparison groups in the frequencies of observed behavior. It is possible that our sample was simply too small to detect a difference between the groups. Further, we should note that the assessment unit was the eighth Seeds of STEM unit that the intervention classrooms experienced, while for the comparison classrooms it was the first one. One explanation could be that even one unit was enough to generate observable behaviors and vocabulary among the children, which speaks to the potential strength of the curriculum. Finally, a third possible explanation came from observing the teachers. The comparison teachers, being recorded for the first time and teaching a new unit without training, relied more closely on the curriculum and followed the instructions and activities provided in the unit plan as written. The intervention teachers, on the other hand, were less reliant on the written instructions and improvised some changes to the unit. They might have been more comfortable and confident in their teaching, having taught seven previous units. While we did find more problem-solving behaviors and vocabulary in the intervention group, we also found evidence for problem-solving behaviors and vocabulary in the comparison group. This is, of course, good news from the curriculum development perspective; however, it reduces the possibility of detecting a difference between the groups.

In addition to these limitations, it is important to note that the EPCOT was not yet validated against other preschool learning measures. The research team is planning to validate the observation tool against other video observation instruments as well as the average of classroom assessment scores. In addition, the findings were only based on post-curriculum data. Future studies comparing intervention classrooms with "business-as-usual" (i.e., true control) classrooms without any overlap in unit coverage, and using pre- and post-test measures, would help shine light on the effectiveness of the tool in detecting the impact of the curriculum. The research team is also interested in exploring the teachers and classrooms that elicited the most behaviors to learn more about characteristics that contribute to successful problem-solving in early childhood.

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Impacts on Head Start Dual Language Learning Children's Early Science Outcomes

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Abstract: The present study examined the roles that language of assessment, language dominance, and teacher language use during instruction play in Dual Language Learner (DLL) science scores. A total of 255 Head Start DLL children were assessed on equated science assessments in English and Spanish. First overall differences between the two languages were examined, then associations between performance on science assessments were compared and related to children's language dominance, teacher quantity of English and Spanish, and teachers' academic science language. When examined as a homogeneous group, DLLs did not perform differently on English or Spanish science assessments. However, when examined heterogeneously, Spanish-dominant DLLs performed better on Spanish science assessments. The percentage of English and Spanish used by teachers did not affect children's science scores. Teachers' use of Spanish academic science language impacted children's performance on science assessments, but English did not. The results have implications for the assessment of DLLs and teacher language use during instruction.

Keywords: early science education; dual language learners; low-income; teacher language use; preschool

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1. Introduction

Throughout the United States, the number of jobs in Science, Technology, Engineering, and Math (STEM) is on the rise [1,2]. However, Hispanic people are disproportionately underrepresented in STEM careers [3]. While they make up 18% of the population in the US [4], they hold only 7% of STEM jobs [2,3]. Thus, there is a need to ensure that early educational experiences are providing opportunities for young Hispanic children to build foundational knowledge in the STEM domains [5]. The current study aims to investigate the assessment methodology used to measure early science learning for young Hispanic Spanish–English Dual Language Learning (DLL) children. Previous studies that include DLL children typically determine language of assessment through a single method (e.g., teacher or parent report) [6]. However, many factors (e.g., teacher language use) influence DLL children's development and could play a role in determining which language(s) are appropriate for assessing them. Furthermore, decisions about language of assessment could potentially impact inferences made about DLL children's development. Thus, the present study examines how the language of assessment, dominant language, and teacher language use impact Hispanic Spanish–English speaking children's performance on a measure of early science learning.

The current study aims to shed light on the early science experiences of Hispanic Spanish–English DLL children. DLLs are defined as children, typically under the age of eight, who are learning two languages [7,8]. DLL children's languages can be learned simultaneously (i.e., began learning both before age three) or sequentially (i.e., began learning one before age three and one after age three) [9]. While not all Hispanic children learn Spanish, the present study focuses on the subset of preschool children who are learning English and Spanish, as they are disproportionally more likely to live in under-resourced homes [10–12]. This puts them at greater risk for an early achievement gap across learning domains such as language, math, and science that persists and widens over time [13–15].

Despite these trends, it is important to note that learning two languages in and of itself is not a liability for academic achievement. There are a great many strengths associated with bilingualism [16–18]. However, the strengths that young Spanish–English DLL children bring into their classrooms are often overlooked in assessment practices. Typically, research surrounding achievement gaps is based on assessments of children in English. This narrow view of achievement may disproportionally misrepresent the performance of Spanish–English DLL children. There may be a need for researchers and practitioners to take a strengths-based approach in assessing their knowledge. More specifically, children are often assessed in one language (as opposed to English and Spanish), while their dominant language and language use during instruction are frequently disregarded entirely. Assessment practices around DLL children have been examined in the context of language skills (e.g., vocabulary, syntax) [19,20]; however, nothing is known about how these factors might impact early science performance. Given the dynamic nature of learning two languages and the need for early support in science, it is critical to examine best assessment practices in science for young Spanish–English DLL children from under-resourced homes.

1.1. Theoretical Framework

The bioecological model [21] states that children are nested within a particular environment. Multiple factors in the environment interact with one another and play a role in children's development. Children are nested within communities, classrooms, and households, all of which impact a DLL's language use and development. In turn, DLL children interact with others in these contexts, in that way contributing to shaping their environment. For example, bilingual teachers could choose to use more Spanish, to better support children's learning in classrooms where the majority of their students are Spanish speaking. Likewise, given this theory [21], if a DLL child grows up in a community where their home language is not used frequently, over time, they may shift toward using their other language more. Conversely, in communities such as Miami-Dade County where this study was conducted, and where Spanish is widely spoken in the community (i.e., by 66% of the population), such a shift may be less likely [22].

In the context of assessment, the bioecological model [21] points to multiple factors that could affect DLL children's performance. At a higher level, decisions about the language of assessment can influence children's scores. For example, researchers and practitioners who only have monolingual English-speaking staff can only assess DLL children in English. Additionally, assessments may only be available in one language. Such factors, in turn, interact with DLLs on an individual level. Some DLL children could be English dominant and perform well on English assessments, while others may be stronger in Spanish. In such circumstances, the language of assessment could potentially obfuscate children's actual knowledge. Furthermore, contextual factors such as teachers' language use could impact children's ability to understand content-specific vocabulary and concepts. For example, if a DLL child who is stronger in Spanish enters a predominantly Spanish-speaking classroom, they may better grasp the content that is taught than if they had entered a mainly English-speaking classroom.

The bioecological model [21] also applies to early science environments. External factors in the community and at home interact with a child's natural curiosity. If this curiosity is fostered over time, children may maintain a spirit of inquiry. Similarly, if scientific inquiry is supported more in one language (e.g., Spanish) than another (e.g., English), DLL children may perform better when assessed in Spanish than they would in English. The current study aims to understand what factors might influence Spanish–English DLL children's science outcomes.

1.2. Methodology of DLL Assessment as a Factor in Performance

As the bioecological model [21] suggests, there are many factors for researchers and practitioners to consider when developing strategies to assess DLLs [6,20,23]. The current paper examines several of the strategies typically used in DLL assessment. The first is to assess DLL children in both of their languages (e.g., [24]). However, there is often a lack of resources (e.g., time, appropriately validated measures, or personnel to administer assessments in both languages) to do so. Another strategy is to assess DLL children in their most proficient, or dominant language. A third approach is to assess DLLs in the language of instruction. This final method is often used in the K-12 education system. Considering all of these strategies is important as the decision often impacts how DLL children are evaluated in their early educational settings. However, given the increased number of DLLs and the growing focus on science in preschool, this study aims to examine how assessment strategy impacts DLL children's performance on a measure of science learning.

1.3. Early Science Education for DLL Children

While few studies in the US have examined preschool DLL children's early science learning experiences [5], research has demonstrated that science is an ideal domain for several key reasons [25,26]. First, science instruction offers DLL children opportunities for hands-on learning, which decreases the cognitive load allocated to language [25,27]. Essentially, having materials physically present for DLL children to manipulate and engage with (e.g., magnifying glasses, blocks, and ramps) aids in learning overall and in learning new words across languages. Teachers can use language to label, describe, and help children to use materials in context, grounding and strengthening DLL children's understanding of science and language. Second, scientific inquiry is collaborative. Finding answers to scientific questions often involves the help of others. Children can be given opportunities to work together and to communicate with peers or teachers while solving problems (e.g., how to make a marble turn a corner in a block and ramp structure). Third, scientific inquiry can be documented and communicated in various ways and does not solely depend on expressive language. Science inquiry or understanding can be exhibited through children's drawings, graphs, and actions. Finally, DLL children bring their cultural understandings and family funds of knowledge into early scientific inquiry [28,29]. Children's questions about the world are sparked by their own experiences (e.g., "Why are there so many iguanas on the road?"). Through science, educators can incorporate children's questions and experiences into learning activities (e.g., "Why do you have to take a plane to visit Colombia?"). Given the promise around science as a learning domain for DLL children, the current study sought to understand factors that might contribute to best practices for assessment in early science. Specifically, this study investigated the impacts of the language of assessment, language dominance, and teachers' use of language (i.e., English and Spanish as well as academic science language) on science outcomes.

1.4. The Roles of Language of Assessment and Dominant Language in DLLs' Performance

Language of assessment and dominant language are important factors to account for in measuring DLL children's outcomes [6,20,23]. Although Spanish–English DLL children are all learning the same two languages, they are a very diverse group with respect to their individual language learning patterns and proficiency [9,30]. Differences in initial language acquisition and levels of exposure place DLL children at varying proficiencies in their two languages. Depending upon language dominance, children score differently on versions of assessments [24,31,32]. For example, one study [32] found that Spanish-dominant DLLs scored better at preschool entry on measures of Spanish vocabulary than English vocabulary [32]. Similarly, English-dominant DLLs scored better at preschool entry and exit on measures of English vocabulary than Spanish vocabulary. However, depending on exposure to English and/or Spanish during preschool, differences between children's language abilities can narrow [32,33]. Studies have found that Spanish-dominant preschoolers make gains in their English language skills in preschool classrooms, narrowing the gap between their languages [32–34]. A shift in dominance, however, is generally not detectable until children have been exposed to several years of English [35]. This indicates that language dominance and language of assessment could both impact children's performance on science assessments in preschool.

Though research has been conducted examining DLL children's differential performance on measures of English and Spanish language [32,33], to the authors' knowledge, there are no studies examining differences in science performance. Notably, while some aspects of science assessment rely on language, some components go above and beyond language. For example, while a child may not know the name of a magnifying glass, they may understand how to use it. This knowledge that occurs over and above vocabulary and language skills [25] speaks to the depth of understanding a child has about the content, thus making it important to understand the impacts that dominant language and language of assessment could have on DLL children's science performance. The current study aims to address this gap in the literature by investigating factors such as the language of assessment and language dominance, which may impact DLL children's scores on English and Spanish science assessments.

1.5. Use of Spanish in Preschool Classrooms

In addition to DLL children's own language abilities and language of assessment, other early environmental factors may play a role in early science performance. In particular, classroom language use has been found to impact DLL children's outcomes [34,36–38]. While little is known about the impacts of the language of instruction on DLLs during science lessons, prior studies have examined the effects of overall English and Spanish use within preschool classrooms. The use of home language (i.e., Spanish) along with English in the classroom has been associated with better outcomes for DLL children [34,36–38]. Supporting DLL children's English and Spanish helps to promote bilingualism, thus supporting their cognitive development [17,39]. Moreover, past research has demonstrated that when more Spanish is used in the classroom, DLL children have better social–emotional [36,40], reading, math [34], and language skills [37,38] compared to their counterparts whose teachers used less or no Spanish. In the preschool years, early education programs (e.g., Head Start performance standards) highlight a need to provide support to DLL children in Spanish and English [41]. This policy reflects findings in DLL research that fostering a strong home language helps children to develop strong English skills [31,42–44]. However, the use of Spanish in classrooms may vary widely, and to date, no studies have examined how Spanish use during science instruction might impact children's science outcomes.

Prior studies, not specific to science education, report little to no Spanish occurring on average in classrooms containing DLL children [34,36,37,45,46]. Many of these studies fully occurred in or involved Head Start funded programs [34,36,37,45,46]. Thus, due to Head Start performance standards, there should be some evidence of support of English and children's home language [41]. However, many studies have reported a large number of classrooms containing DLL children where teachers do not use Spanish at all [34,36,37,45,46]. For example, one study [36] found that DLL children in 23% of classrooms were exposed to no Spanish, and 18% heard very little Spanish (i.e., <5% of the time). Similarly, another study [37] found even less Spanish being used in classrooms and that it was mainly used to give behavioral feedback or directions to children [37]. Additionally, children who maintained high levels of Spanish across the school year received instructions in Spanish, on average, 32% of the time [34]. However, about a third of teaching teams used no Spanish during instruction. Together, these studies indicate that despite evidence that using Spanish is important for children's outcomes, it is generally used infrequently in preschool classrooms comprising Spanish–English DLL children. Given the dearth of literature around preschool teachers' Spanish and English use during science instruction specifically, the current study aims to examine how these factors might impact children's science outcomes.

1.6. Importance of Academic Language

In addition to the sheer quantity of English and Spanish used during science lessons, research in other learning domains suggests that the quality of language is an important factor in children's outcomes [14]. That is to say that the quality of the science-specific vocabulary that teachers use in each language could be an indicator of the science information that children are learning. Although the impact of academic language has been investigated in other learning domains, there is limited research in science and across various languages (including Spanish) [37,47–50]. Previous research demonstrates that providing children with high-quality language improves their vocabulary and language outcomes [37,49]. Science is a learning domain that provides many opportunities to enrich children's vocabulary [51]. For this study, the term "academic science language" is used to describe high-quality vocabulary used by teachers within the classroom that relates to science.

Prior research investigating teacher use of academic science language in preschool has focused on creating science interventions to enrich children's vocabulary [26,47,51–55]. One study found that preschoolers and kindergarteners whose teachers participated in science interventions had higher vocabulary scores [51]. Additionally, research focused on teachers' use of academic language in the context of science has also demonstrated increases in children's use of academic vocabulary [47,54]. Nevertheless, to date, few studies have examined the academic language that teachers use naturally around science, without a fixed science intervention [47,54]. These studies also examined children's vocabulary and not children's science outcomes. Furthermore, academic science language and the impacts on Head Start Spanish–English DLL children in both English and Spanish have yet to be examined. The current study addresses this gap by capturing teachers' academic science language use in both English and Spanish in a structured science lesson and determining whether it relates to preschool DLL children's performance on science outcomes across languages.

1.7. Current Study

There is a gap in the literature regarding DLL children's performance in science across both of their languages. There is also a need to better understand factors that might contribute to their science scores. Most literature surrounding the importance of language of assessment and the role of children's dominant language focuses on the domain of language (e.g., vocabulary, syntax) and not on other critical learning areas such as science [24,31,32]. Furthermore, teacher-level impacts such as language use (i.e., English and/or Spanish) in the classroom could contribute to children's scores on language math, and social–emotional assessments [34,36]. However, to date, there are no studies that examine teachers' English and Spanish use specifically within the context of preschool science. Finally, prior studies indicate that the academic language that teachers use impacts children's outcomes [37,49]. Again, these findings typically examine children's language outcomes and not science performance. The current study aims to fill multiple gaps in the literature around science assessment for DLL children from under-resourced homes by answering the following research questions:

1. First, this study examines if, overall, DLL children performed significantly better on a science assessment in English or Spanish. Given the unique Spanish-dominant community of the study participants, this aim remains exploratory. DLL children in this sample may be enrolled in schools where teachers do not primarily speak English. Thus, children may hear more Spanish and perform better on Spanish science assessments if they enter preschool with more Spanish skills compared to English skills;
2. Second, this study examines whether dominant language impacts performance on a science assessment in English and Spanish. Based on previous literature, it is hypothesized that DLL children's dominant language will be associated with their scores on both English and Spanish science assessments [32];

3. Third, this study investigates the association between teachers' language of instruction (i.e., English and Spanish) during science lessons and DLL children's performance on an assessment of science learning in both English and Spanish. It is hypothesized that DLL children whose teachers use more English will perform better on the English science assessment. It is also hypothesized that DLL children whose teachers use more Spanish will have higher scores on science in Spanish [34,56];
4. Fourth, this study examines the relation between the language of instruction when using academic science language on DLL children's performance on science assessments (i.e., English and Spanish). It is expected that DLL children whose teachers use more academic science language in English will have higher scores on the English science assessment [37]. Finally, it is hypothesized that DLL children whose teachers use a higher amount of academic science language in Spanish will have higher scores on the Spanish science assessment.

2. Materials and Methods

2.1. Participants

This cross-sectional study was conducted within the context of a larger study, Enfoque en Ciencia, with the participation of Head Start Centers across a large urban area in the Southeastern United States. Head Start is a federally funded preschool program in the United States. Head Start includes hundreds of early learning centers across the US that aim to ensure children from low-income homes have the academic and social–emotional skills to succeed in the K-12 education system. They mainly serve children between the ages of three and five who live in low-income households (i.e., below 130% of the federal poverty guidelines). Performance Standards issued by Head Start state that the program supports language development in both English and children's home language. However, no specific guidelines define the amount of English and Spanish that should be used [41]. The actual language used in Head Start classrooms depends on local programs and individual teachers (e.g., it could range from 5% English to 95% English). The classrooms in this study were not involved in purposeful bilingual or dual immersion programs. However, the schools in this study were located in areas where Spanish was very prevalent. Spanish was spoken by 66% of the population in Miami-Dade County, and 25% spoke only English [57]. Centers (N = 8) participating in the larger project were informed about and consented to the current project including directors, teachers, teaching assistants, and families. Centers involved in this study used HighScope, a research-grounded curriculum that promotes active learning, yet at the time of data collection did not have a science-focused component.

The current study was housed within a larger project validating an early science assessment measure for Spanish–English-speaking children from under-resourced homes. There was no intervention involved, and the study consisted of assessing children in the fall and spring of the 2017–2018 academic year. Center directors were approached, and if they were interested in their center participating, teachers and parents were approached. Participation in the study was voluntary, and teachers and parents were asked for consent and provided with a detailed description of what the study involved (e.g., classroom observations, child assessments, etc.). In addition, parents had to return their signed consent form for their child to participate in the observation portion of the study. To participate in this study, and as a part of the larger study, children had to score at least a 2 out of 20 on the English language screener and a 6 out of 20 on the Spanish language screener. These cutoff scores were set purposefully low to capture a realistic representation of the DLL population. Additionally, these cutoffs were used to ensure that children had some level of English and Spanish, thus making them Spanish–English DLLs. The less stringent cutoff score for English follows the assumption that children who speak Spanish at home and are newly developing their English skills in school would be acquiring English skills during the study. A total of 255 Spanish–English DLL children participated in the current study in the 2017–2018 school year. Children ranged in age from 3 to 5 years old (M = 48.66, SD = 6.60); 46% were girls, and 21% were English dominant.

Lead and assistant teachers (*N* = 66) in this study were all female and had between 1 and 25 years of teaching experience (*M* = 12.52, *SD* = 6.25). Eighty-two percent of teachers reported that Spanish was their primary language. Teachers in this study reported speaking varying levels of English and Spanish. Most teachers reported speaking Spanish "very well" (n = 41) or "well" (n = 10). Fewer teachers reported speaking Spanish "not well" (n = 10) or "not at all" (n = 5). Some teachers stated that they spoke English "very well" (n = 14), while most reported speaking it "well" (n = 22) or "not well" (n = 22). Six teachers reported that they did not speak English at all. Teachers who agreed to take part in the study were given gift cards as compensation for their time spent participating in the study. Teachers were also asked if they had received any professional development around science. Overall, most teachers reported having a moderate (n = 35) or minimal (n = 15) amount of professional development around early science education. Some reported having a great deal (n = 12) of professional development around early science, and a few reported having no training in early science education (n = 4).

2.2. Procedure

Data collectors included undergraduate and graduate research assistants. All data collectors were rigorously trained on the administration of assessments. Most data collectors were Spanish–English bilinguals (88%). The language screener was administered by bilingual research assistants as there were components that required administration (i.e., by the research assistants) and responses (i.e., from children) in English and Spanish. Because the science assessment was delivered on touchscreen laptops (i.e., all instructions and items were delivered by the program in English for the English version and in Spanish for the Spanish version), the research assistants only monitored administration (e.g., setting up the laptops, monitoring that children were staying on task).

Children were screened for language dominance in the fall of 2017 to determine their English and Spanish language abilities (see Measures Section below for more details). Dominant language results were used to counterbalance the order of administration for the science assessments. Thus, half of the English-dominant children received the Spanish science assessment first, while the other half received the English science assessment first. This counterbalancing procedure was also used for Spanish-dominant children. Administration of the science assessments in English and Spanish occurred in the spring of 2018.

Participating teachers reported their demographics and language proficiency in English and Spanish in the spring of 2018. Teachers also consented to be videorecorded while conducting a science lesson of their choosing. Videos were recorded in each classroom, one morning, for 15 to 20 min. Teachers were asked to conduct a science lesson in whichever language(s) they typically used. They were allowed to choose whatever topic they wanted; most chose to perform a Physical Science lesson (n = 18). The next most frequent type of lesson chosen was Life Science (n = 8), followed by Earth and Space Science (n = 5) and Engineering and Technology (n = 3).

Videos of science lessons were transcribed by research assistants using the Systematic Analysis of Language Transcripts (SALT) Software conventions [58]. Research assistants were trained using materials available on the SALT website (e.g., videos, practice audio files, and master transcripts). In line with SALT coding procedures, the resulting transcripts were segmented into C-Units, or "an independent clause with all of its modifiers" [58]. Transcripts were then coded for teachers' use of English and Spanish, use of academic words, and science language.

2.3. Measures

2.3.1. Language Screener

Children were assessed in the fall on the PreLAS2000 [59], a language screener for preschool children, available in English and Spanish. The PreLAS2000 was used to capture children's language abilities to determine language dominance and DLL eligibility to participate in the study. Two subtests were used for assessing English and Spanish, Simon Says and the Art Show. The Simon Says subtest contains ten items and measures children's receptive language ability, while the Art Show also contains ten items and captures children's expressive abilities. The use of these two subtests has been validated with ethnically diverse Head Start children [60]. Reliability for the "Simon Says" and "Art Show" subscales is high, with Cronbach's alphas of 0.88 and 0.90, respectively [59].

2.3.2. Science Achievement

Children were assessed in the spring using items from the Lens on Science [61] and Enfoque en Ciencia assessments to determine their knowledge of science concepts. Lens and Enfoque are the equated versions of the same science assessment; they only differ by the language of administration: English or Spanish. Lens and Enfoque items assess science knowledge as it relates to the Framework for K-12 Science Education [62] in the following areas: scientific and engineering practice skills, crosscutting concepts, and science content from "life science", "earth and space sciences", "technology and engineering", and "physical and energy sciences". Items cover a range of difficulty levels normed on a sample of 1750 English monolingual children and 1174 Spanish–English DLL preschool-aged children in Head Start. Children received equivalent forms of Lens and Enfoque, distributed evenly in both difficulty and in the content area, to ensure that the subsets of items chosen in English and Spanish were equivalent. Therefore, DLL children did not receive a more difficult form in either language. Items were calibrated using the dichotomous Rasch model scaled to have a mean item difficulty of zero and unit-logit metric. On this scale, 0 is the mean of the norming sample and 1 is the standard deviation. For example, if a child receives a score of 0, it means they scored on average as well as children in the norming sample. If a child receives a 1, they scored a standard deviation above the mean, and if they receive a score of -1, they would be one standard deviation below the mean. The average standard error of the Rasch ability estimate was 0.34 for both Lens and Enfoque, which is equivalent to a score reliability of 0.86 [61].

Lens and Enfoque are administered on the same touchscreen computer platform. Children are asked to sit in front of a touchscreen device, and items are presented visually to children one at a time. Children listen with headphones to prompts instructing them on how to respond. For example, an item measuring children's understanding of the concept of melting might show a picture of a strawberry inside an ice cube sitting in the sun. With the initial picture still visible, three choice pictures then appear below it, and children are instructed to "touch the picture that shows what the strawberry looks like after having sat in the sun". A trained research assistant supervises the test administration process. Prior to administration of the assessment, children must pass a screener, also administered on the touchscreen device. This screener demonstrates a child's ability to follow the instructions and correctly respond to each of the three item formats. The administration took approximately 20 minutes for each form.

2.3.3. Quantity of Teacher English and Spanish

Transcripts of teacher talk during the science lesson were coded using Atlas.ti software by research assistants. Each word spoken by a teacher was coded as "English" or "Spanish". All words were counted as "tokens", meaning that each time a word is used, it counted toward the total count of English or Spanish. For example, the word "animal" could be used once in English and twice in Spanish. "Animal" would then be coded as "English" once and "Spanish" twice. Words were not coded as English or Spanish if they were names, proper nouns, filled pause words (e.g., um, ah, ok, eh), or singing. These words were not coded because it was often difficult to determine what language the speaker intended to use. For example, a child's name could be "Daniela" and pronounced in English or Spanish. If the coder was not sure if a word was English or Spanish (e.g., metal, animal), they referred to the original video.

2.3.4. Teacher Academic Language

To code teacher academic language, two lists of the words most commonly used and heard by DLL children were used to filter out “common” language [63]. If words were not included on this list, they were deemed “academic”. The initial English list contained a total of 1109 word types (e.g., car). The Spanish list contained 949 word types. After filtering these words out, conjugations, verb tenses, plurals, and diminutives relating to the words on the lists were removed. According to the rules outlined by Schick et al. (2019), variations that changed words to adverbs were considered more sophisticated and left on the “academic” list. A total of 1360 English common words, including conjugations and plurals of words on the original lists (i.e., both car and cars), and 1714 Spanish common words were filtered out.

2.3.5. Teacher Academic Science Language

To determine how much academic science language teachers used, a codebook was created using the preschool version [64] of the K-12 Conceptual Science Framework [62]. A graduate student and undergraduate research assistants coded scientific and engineering practices and core ideas that teachers used in both English and Spanish. Science codes were coded at the C-Unit level. All research assistants were rigorously trained and passed reliability to code science language with a Krippendorf’s alpha of 0.67 or higher [65]. For scientific and engineering practices, the average alpha was $a = 0.82$, and for core ideas, $a = 0.79$.

3. Results

3.1. Descriptives

All data were examined for outliers, skewness, kurtosis, and collinearity using SPSS version 26 [66]. All variables met the assumption of normality [67]. Before running analyses, continuous variables were centered. Descriptive statistics for children’s Spanish and English science scores and teacher speech are displayed in Table 1. There were no differences between the average percentages of English ($M = 47.97$, $SD = 38.10$) and Spanish ($M = 52.03$, $SD = 38.10$) used by teachers, $t(33) = 0.31$, $p = 0.76$. In comparison to breakdowns of English and Spanish use in prior studies (see [36]), teachers used a good deal of Spanish overall. In 2.9% of science lessons, teachers used no Spanish. In 14.71% of science lessons, teachers used Spanish < 5% of the time. In 14.71% of classrooms, it was used between 5% and 25% of the time. In 14.71% of classrooms, teachers used Spanish between 25% and 50% of the time. Finally, in 52.94% of science lessons, teachers used Spanish more than 50% of the time during the lesson. On average, teachers used more Spanish academic science words ($M = 74.74$, $SD = 73.90$) than English science academic words ($M = 31.24$, $SD = 35.91$), $t(33) = 2.80$, $p < 0.01$.

Bivariate correlations for all variables including control variables were examined and are presented in Table 2. Children’s English and Spanish science scores were moderately positively correlated ($r = 0.52$). Age was also moderately positively associated with children’s English ($r = 0.40$) and Spanish ($r = 0.45$) science assessments. The overall percentage of teachers’ English use was positively correlated with children’s English science outcomes ($r = 0.15$), while the overall percentage of Spanish used was negatively related to children’s English science outcomes ($r = -0.15$). Teachers’ use of Spanish academic science words was negatively associated with children’s performance on the English science assessment ($r = -0.17$).

Independent *t* tests were conducted to determine whether there were significant differences between children’s performance on English and Spanish equivalent forms. There were no significant differences between boys’ ($M = -0.01$, $SD = 0.85$) and girls’ ($M = -0.01$, $SD = 0.85$) English science assessments, $t(249) = 1.40$, $p = 0.16$. There were also no significant differences between boys’ ($M = 0.16$, $SD = 0.97$) and girls’ ($M = 0.32$, $SD = 0.82$) Spanish science assessments, $t(249) = 0.03$, $p = 0.98$.

Table 1. Descriptive statistics for child and teacher level variable.

		n	*M*	*SD*	Min	Max
Children's English Science Assessment	Spanish Dominant	197	−0.12	0.81	−2.11	2.69
	English Dominant	54	0.39	0.90	−1.31	2.34
	Overall	251	−0.01	0.85	−2.11	2.69
Children's Spanish Science Assessment	Spanish Dominant	198	0.22	0.94	−2.11	3.92
	English Dominant	53	0.28	0.75	−0.97	2.35
	Overall	251	0.23	0.90	−2.11	3.92
Teachers' Percentage of English		34	47.97%	38.10	0.37	100.00
Teachers' Percentage of Spanish		34	52.03%	38.10	0	99.63
Teachers' Number of English Words		34	651.91	626.46	5	2522
Teachers' Number of Spanish Words		34	784.15	677.36	0	2184
Teachers' Number of English Academic Science Words		34	31.24	35.91	0	143
Teachers' Number of Teachers' Spanish Academic Science Words		34	74.74	73.90	0	230

Note: Science scores are measured using the dichotomous Rasch model scaled to have a mean item difficulty of zero and a standard deviation of 1.

Table 2. Bivariate correlations.

	1	2	3	4	5	6	7	8
1. English Science Assessment								
2. Spanish Science Assessment	0.52 ***							
3. Age	0.40 ***	0.45 ***						
4. Sex	−0.01	−0.09	0.02					
5. Dominant Language	0.24 ***	0.02	0.13 *	0.13 *				
6. Percentage of English	0.15 *	0.05	0.12	−0.03	−0.01			
7. Percentage of Spanish	−0.15 *	−0.05	−0.12	0.03	0.01	−1.00 ***		
8. Number of English Academic Science Words	0.03	0.05	0.07	0.06	0.09	0.47 **	−0.34 *	
9. Number of English Academic Science Words	−0.17 **	−0.11	−0.14	0.07	−0.20	−0.87 ***	0.94 ***	−0.27

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Numbers 1–5 are child level variables. Rows 6–9 are teacher level variables.

3.2. DLL Children's Science Outcomes in English and Spanish

A repeated-measures ANCOVA was conducted using SPSS to examine potential differences in DLL children's performance on their English and Spanish science assessment. Results indicated that there was no difference between children's scores on English ($M = -0.01$, $SD = 0.85$) and Spanish ($M = 0.23$, $SD = 0.90$) science assessments controlling for age and sex, $F(1, 243) = 0.17$, $p = 0.68$.

Mplus version 8.3 [68] was used to examine aims 2 through 4 (i.e., 2. dominant language associated with children's science outcomes in English and Spanish, 3. the language of instruction associated with children's science outcomes in English and Spanish, and 4. teacher's academic science language related to DLL children's performance on science assessments in English and Spanish). Intraclass correlation coefficients (ICCs) were calculated to determine the amount of variance in children's science scores that is attributable to the classroom level. ICCs indicated that classroom-level factors comprised 0% of the variance in children's Spanish science assessment and 0.76% of the variance in children's English science assessment. As there was some variance at the classroom level in children's science outcomes, children were nested within classrooms (i.e., type = two-level).

3.3. Dominant Language and Science Scores

Hierarchical linear modeling was conducted for aim 2, to determine if dominant language was associated with children's science outcomes in English and Spanish. Model fit was good across multiple fit indices, including X^2 (3, N = 255) = 7.65, $p > 0.05$, RMSEA (0.08), CFI (0.96), and SRMR (0.05). When controlling for children's age and sex, dominant language was associated with children's English science scores, $b = 0.20$, $p < 0.01$; however, it did not relate to children's Spanish science scores, $b = -0.02$, $p = 0.64$.

A follow-up repeated-measures ANCOVA was conducted for aim 2, to determine the nature of the relation between dominant language and language of assessment. There was no main effect for dominant language, $F(1, 242) = 2.99$, $p = 0.09$. There were no significant differences between English-dominant and Spanish-dominant children's Spanish science scores. There was, however, an interaction between dominant language and performance on science assessments, F (1, 243) = 11.20, $p < 0.001$, such that English-dominant children ($M = 0.39$, $SD = 0.90$) performed significantly higher on English science assessments than Spanish-dominant children ($M = -0.12$, $SD = 0.81$). See Figure 1 for follow-up results examining differences between science scores based on dominant language.

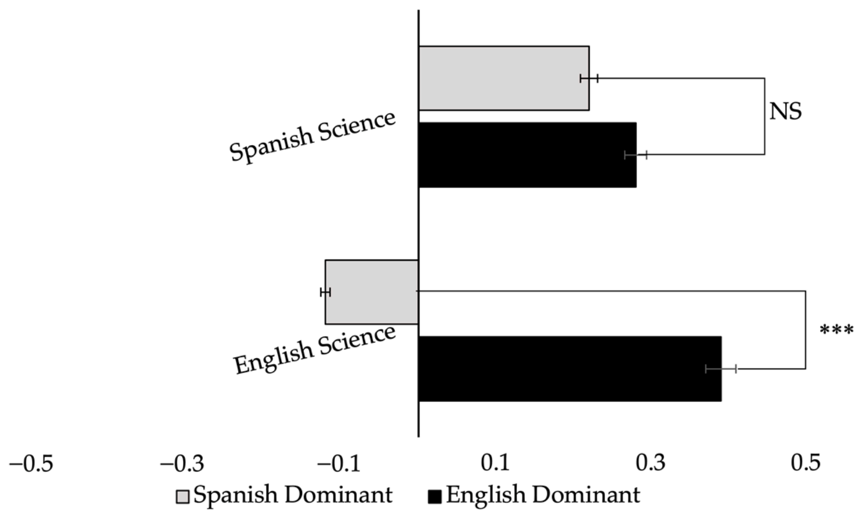

Figure 1. Note: *** $p < 0.001$. English and Spanish science scores by dominant language.

3.4. Teachers' Use of English and Spanish in Structured Science Lessons

To determine if the percentage of teachers' English and Spanish was associated with children's English and Spanish science scores, models were also run in Mplus, nesting children within classrooms. See Figure 2 for the conceptual model. When examining the relation between the percentage of English that teachers used during a science lesson and children's science outcomes, model fit was good, X^2 (3, N = 255) = 4.88, $p > 0.05$, RMSEA = 0.05, CFI = 0.99, and SRMR within = 0.03, controlling for children's age, sex, and dominant language, and teachers' primary language. SRMR between (0.13) was decent. Teachers' English use did not predict children's English science scores ($b = 0.90$, $p = 0.06$) or children's Spanish science scores, $b = -0.06$, $p = 0.92$.

As the percentage of Spanish language used by teachers was linearly dependent upon their English percentage, model fit was also excellent for the model containing teachers' percentage of Spanish, X^2 (3, N = 255) = 4.88, $p > 0.05$, RMSEA = 0.05, CFI = 0.99, and SRMR within = 0.03. SRMR between (0.13) was decent. The percentage of Spanish used by teachers was not associated with children's English science assessments ($b = -0.90$, $p = 0.06$) or children's Spanish science scores, $b = 0.06$, $p = 0.92$.

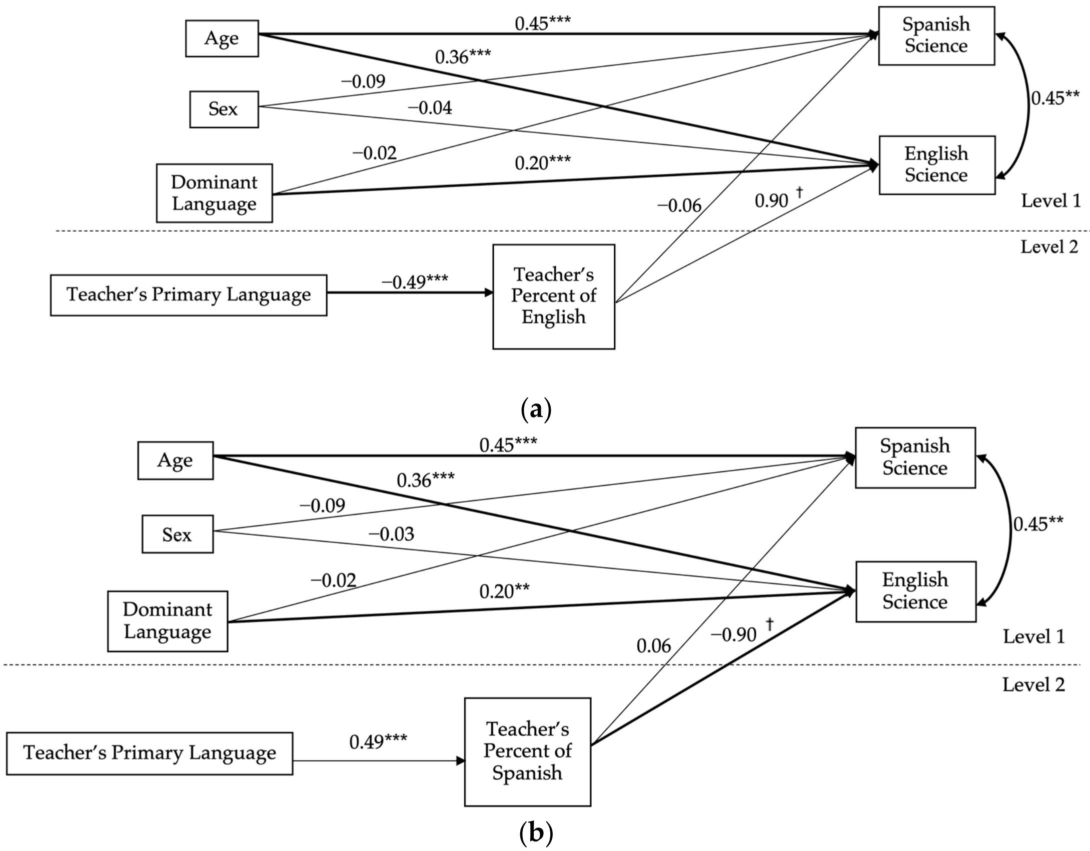

Figure 2. Note: † $p < 0.10$, ** $p < 0.01$, *** $p < 0.001$. (**a**) Percentage of teachers' English associated with children's science outcomes; (**b**) percentage of teachers' Spanish associated with children's science outcomes.

3.5. Teachers' Use of Academic Science Language English and Spanish in Structured Science Lessons

Models were also run in Mplus to determine the relation between teachers' academic science language and children's science outcomes, nesting children within classrooms. For the model containing Teachers' use of academic science English, model fit was excellent according to the chi-square test of model fit (X^2 (8, N = 255) = 13.10, p = 0.11), RMSEA (0.05), CFI (0.97), and SRMR within (0.04). It was poor for SRMR between (0.27). Controlling for children's sex, age, and dominant language, teacher's primary language, teacher's highest education, and overall percentage of English used, teachers' academic science English was not associated with children's English ($b = -0.13$, p = 0.85) or Spanish science scores (b = 0.24, p = 0.66). See Figure 3 for models.

When examining the relation between teachers' academic science language in Spanish and children's science scores, model fit was also excellent for the chi-square test of model fit (X^2 (8, N = 255) = 8.12, $p > 0.05$), RMSEA (0.01), CFI (0.99), and SRMR within (0.03). It was poor for SRMR between (0.18). Teachers' academic science Spanish language was not related to children's Spanish science scores, $b = -0.29$, p = 0.59. Academic science Spanish was negatively associated with children's English science scores, $b = -0.89$, p = 0.049. The more academic science language that was used by teachers, the lower children's English science assessment scores were.

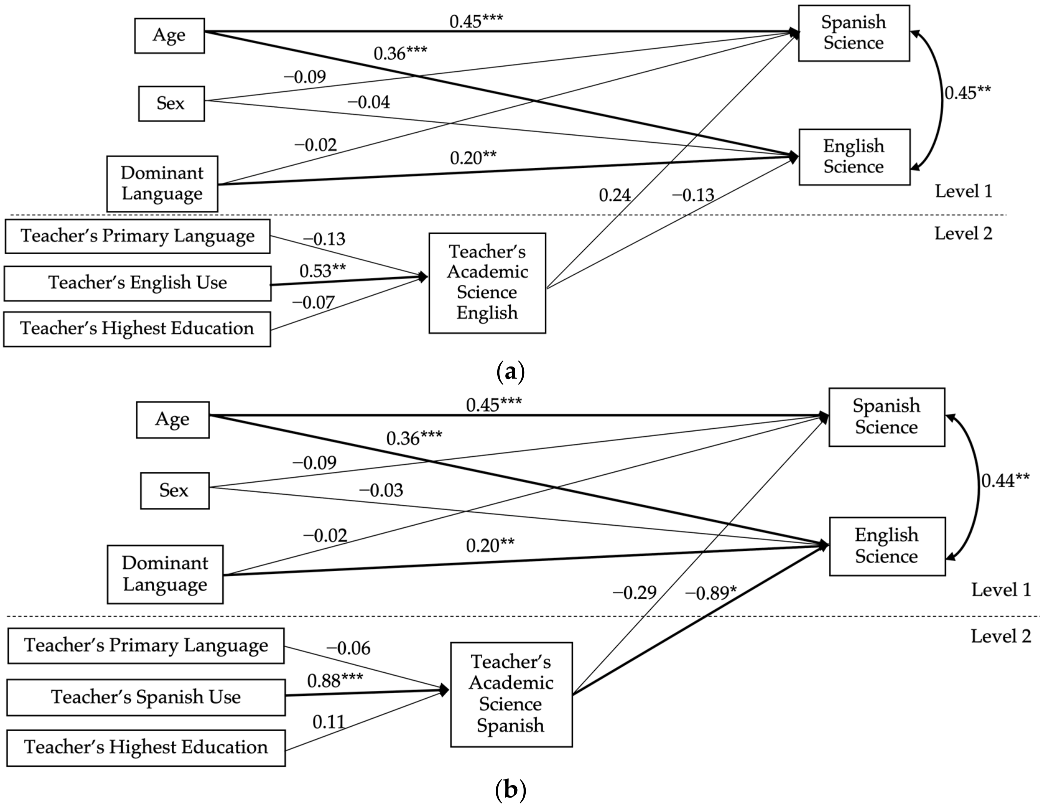

Figure 3. Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. (**a**) Teachers' academic science English associated with children's science outcomes; (**b**) teachers' academic science Spanish associated with children's science outcomes.

4. Discussion

The purpose of this study was to examine factors that might influence Spanish–English DLL children's performance on a science assessment in both of their languages. DLL children, when treated as a homogeneous group (i.e., when no distinctions between English- and Spanish-dominant children were made), did not perform differently on English and Spanish science assessments. However, when examined as heterogeneous groups (i.e., English dominant versus Spanish dominant), Spanish-dominant children performed higher on their Spanish science assessment than their English science assessment. Teachers' use of academic science Spanish use was negatively related to DLL children's performance on the English science assessment. No other teacher language use affected children's performance on English or Spanish science assessments.

4.1. Role of Language of Assessment in Performance

4.1.1. Assessment of DLL Children as a Homogeneous Versus a Heterogeneous Group

DLL children are not a monolith. Thus, it is important to investigate how language differences within group [30,69], such as dominant language, affect assessment. When DLL children were assessed as a single homogeneous group, there were no differences in science scores between languages. This aim was exploratory; however, it was an important step in the analyses because it demonstrates the potential for an erroneous conclusion (i.e., that language of assessment does not matter). However, when dominant language was accounted for, children did perform differently on English and Spanish science assessments.

It was hypothesized that dominant language would be associated with children's scores on both English and Spanish science assessments. However, this hypothesis was only partially supported, as dominant language only predicted performance on English assessments. English-dominant children performed higher on English science assessments than Spanish-dominant children performed on English science assessments. There were no differences between Spanish- and English-dominant children's Spanish science scores.

This differential effect of language dominance suggests that it is especially important to consider the role of dominant language when assessing Spanish-dominant children. The results of this study align with previous research that suggests that Spanish-dominant DLL children tend to perform higher on measures assessed in their dominant language [20,32]. This study extends research examining DLL children's performance on language assessments, to early science, a domain that not only requires language skills but critical-thinking and problem-solving skills, as well [70,71]. Because Spanish-dominant children performed higher on Spanish science assessments, future studies and school programs should consider assessing DLL children in their dominant language (if not both languages) on measures of language and in other learning domains such as science.

4.1.2. English-Dominant Children's Science Scores

In contrast to prior studies which found that English-dominant children did not score as well on Spanish assessments [32], the current study found that English-dominant children were performing on par with their Spanish-dominant peers. This pattern may have emerged in the current sample for several key reasons. First, English-dominant children may have had high to moderately high language skills in both languages. Second, most of the children in the sample were Spanish dominant. Third, the majority of teachers in this study were proficient in Spanish and used it within the classroom. Finally, the community in which this study occurred was a Spanish-language dense area.

At the beginning of the school year, English-dominant children had an average English language score of 14.13 and an average Spanish score of 8.52 (both out of 20). On average, Spanish-dominant children began the school year with an English score of 5.71 and a Spanish score of 15.72. English-dominant children may be entering the preschool program with higher levels of Spanish than Spanish-dominant children have in English, as demonstrated by their Spanish language screener scores. However, this study did not measure children's language ability at the time of the science assessment in the spring, and thus, future studies should examine growth in Spanish skills over time.

Furthermore, on average, teachers reported having about 95.4% of their classroom comprising DLL children. The majority of DLL children sampled from the classrooms were Spanish dominant (i.e., 80%). DLL children in this study were also still very young and may have only recently started school. Given the large proportion of Spanish-dominant peers, children may have had more opportunities to continue using Spanish within their classroom (as opposed to English). Given opportunities to interact with predominantly Spanish-dominant peers, it may be that English-dominant children had more occasions to use and improve their Spanish skills during the year.

Children in the current sample were enrolled in preschools where English and Spanish were both used frequently. When assessed as a single group, English-dominant DLL children may have performed equally well on English and Spanish science assessments because on average, they heard more Spanish during instruction (i.e., use of 47.97% English and 52.03% Spanish) than in previous studies, thus allowing them to continue developing their home language [34,36,37,45]. Teachers used Spanish, on average, over half of the time, whereas teachers in other studies typically spoke Spanish much less, if it was used at all [34,36,37,45,46].

Additionally, the metropolitan area in which this study took place has the highest population of Hispanics in the US [72]. Over 66% [22] of the people in this area report speaking Spanish, while nationally, only 12.85% [73] of the population reports speaking Spanish. Within this area of the country, the maintenance of Spanish may be more desirable due to cultural norms [57]. Reports of language use in this metropolitan area demonstrate that Spanish is used by people of all socioeconomic statuses (SES), including people of higher income. Researchers indicate that the continued use of Spanish by people of all SES levels may lead to Spanish being highly valued and perpetuate the use of the language within the region [57]. Prevalence of Spanish within the community may promote teachers' and children's use of Spanish in the classroom, which may be another reason why English-dominant children in this sample performed equally on science assessments.

4.2. Percentage of Teacher English and Spanish Use

The percentage of English and Spanish that teachers used in the classroom was not significantly associated with children's science scores. These findings did not align with prior studies which demonstrated that when teachers used more Spanish, children performed higher on measures of academic achievement [34,36,38]. Previous literature found that in classrooms where teachers used "some Spanish" (observer report of 49% on average), children had higher Spanish abilities [38]. In the current study, teachers used about as much Spanish as in the previous literature. However, Spanish language use did not affect children's Spanish science scores. One factor that could impact how teacher language affects children's assessment performance is classroom quality [34,36,38]. Classrooms where teachers used some Spanish had higher ratings of quality than classrooms where teachers did not [38]. It was in these high-quality, "some Spanish" classrooms where children exhibited higher gains in Spanish language. Additionally, in classrooms with more Spanish used by the teacher and higher quality teacher emotional support, children had higher reading and math scores [34]. The current study did not control for classroom quality in its analysis of teacher Spanish and English use, which may account for the null findings. Despite the null findings, this study contributes to the literature on teacher language use with DLL children by providing a detailed examination of the quantity of English and Spanish (i.e., word-by-word analysis instead of self-report, observer report, or time sampling) in the context of a science lesson.

4.3. Academic Science Language in Preschool Classrooms

The amount of academic science language teachers used in Spanish was inversely associated with children's science scores in English. Academic science language in English did not predict children's outcomes in science as hypothesized. An overwhelming number of studies have demonstrated that academic language positively relates to children's vocabulary outcomes [37,48–50]. However, these studies did not investigate the impacts of teachers' academic language use on DLL children or science assessments.

Academic science Spanish may have been inversely related to children's English scores because it was highly correlated with the amount of English and Spanish that teachers were using. That is, teachers who used more academic science Spanish tended to use more Spanish overall, and less English overall. It may be that the children in this sample were exposed to more Spanish overall, including within science settings. Children's primary exposure to English is likely through their teachers, so when teachers use less English, children do not perform as well on their English science assessments. Although teachers used more academic science Spanish, this should not be considered detrimental to children's science scores, as previous studies have demonstrated the importance of Spanish in DLL preschool classrooms [34,36,38]. Alternatively, this finding suggests a need to also consider the language use of teachers when deciding what language(s) to use when assessing Spanish–English DLL children's science.

Additionally, English and Spanish academic science language was dispersed between two languages for teachers and children. This study took a unique perspective in examining both English and Spanish children's science scores; however, it may be important to take a more holistic approach when examining the impacts of academic language on children's science outcomes. Most prior studies examining the impact of academic language on children's outcomes were conducted with teachers who only used English and only investigated children's English scores [49,50]. One study did find that when teachers used more complex language in English, it was positively associated with children's bilingual outcomes [37]. It is possible that the effects of a combination of teachers' academic science language in English and Spanish may predict a combination of DLL children's English and Spanish science scores (i.e., a conceptual score). Studies examining the efficacy of conceptual scoring have found that it improved DLL children's performance on language assessments above their scores when tested in only one language [74,75]. Despite the importance of conceptual scoring, past studies have predominantly examined its effects in the context of language abilities and do not extend it to other domains, such as science.

Furthermore, it is possible that teacher academic science language alone, without good pedagogy, does not positively relate to children's science outcomes. Science is a relatively new area of focus in early childhood education, and most preschool classrooms do not include it as part of their curriculum [76,77]. Thus, it may have been rare for a teacher to intentionally incorporate science into their lesson plans. This study attempted to circumvent the lack of intentional science present in early childhood education by examining academic language as it related to the Early Science Framework (e.g., coding for Scientific and Engineering Practices and Core Ideas) in context. Similar studies examined teachers' use of math language and found that when high-quality math pedagogy was paired with a strong understanding of the content, teacher language was associated with children's outcomes in math [78]. The present study may not have found similar results because it only captured the content of the lesson and not pedagogy or the teacher's understanding of science content. For the teacher's academic science language to have a positive effect on children's science scores, it may be necessary to ensure that teachers have a good pedagogy to enact an effective science lesson. Teachers may also need to have a strong understanding of children's developmental level and be able to balance this with both science content and good pedagogy. Thus, it may be important to pair academic language with a measure of science lesson quality. Measures that assess the quality of preschool science lessons are becoming more readily available [79,80]. Future studies should consider controlling for the quality of the science lesson when examining teachers' academic science language.

4.4. Implications for Practice

The present study has implications for researchers, practitioners, and policymakers. First, this work brings attention to an understudied learning domain, i.e., early science. Children are naturally curious about the world around them and express great motivation for learning science during the preschool years [81]. Young children ask questions about why things happen (e.g., "Why don't my shoes fit anymore?"), constantly carry out experiments (e.g., dropping a sippy cup off of a highchair to see if a caregiver will pick it up each time), and make observations (e.g., "It's too cold!") [82]. Despite this early motivation to engage in scientific inquiry, by high school, students' motivation around scientific inquiry declines [83]. This demonstrates a need to begin supporting children's scientific curiosity early and to continue fostering it as they develop. However, to date, many studies focus on language, math, and social–emotional skills. This study sought to highlight the importance of support in this early learning domain by examining factors that related to DLL children's science outcomes.

Results from this study indicate that it is important for teachers working with DLL children to be cognizant of the language in which they administer assessments. This is especially true for DLL children who are Spanish dominant. When Spanish-dominant children were assessed in English, they performed worse on English science assessments, illustrating a need for researchers and practitioners to screen DLL children for their dominant language before administering assessments or to administer them in both languages. It is also important for researchers, practitioners, and policymakers to be critical when interpreting scores from DLL children. For example, if an English science assessment is given to a Spanish-dominant child, educators and stakeholders should recognize that their score may not accurately represent their science abilities.

Although the language of instruction did not always impact children's outcomes, this study provides insight into the language that early childhood teachers use with DLL children in the context of science. Teachers' use of academic science Spanish did impact children's English science outcomes, indicating that teacher language use is an important factor to consider when assessing DLL children. This study can be particularly useful for metropolitan areas where Spanish is more prevalent in the community and may be affecting patterns of loss or maintenance.

Findings from this study can also inform practice in early childhood at a national level by providing information about how the home language and English are being supported within classrooms, specifically within the context of science instruction. Within the context of this study, teachers on average demonstrated that they used both English and Spanish equally, showing that these sites are implementing early education best practices (i.e., Head Start Performance Standards) around support for DLL development [41].

4.5. Limitations and Future Directions

The important implications for researchers, practitioners, and policymakers from this study suggest a number of future research directions. To better understand the nature of the difference between DLL children's English and Spanish science scores, future studies may want to include a larger sample of children. Although not statistically significant, there was a trend level finding, where the percentage of English that teachers used positively predicted children's English science scores. Given a larger sample, this may have been statistically significant and might indicate that Spanish–English DLL children's English science assessments are influenced by teachers. However, further studies are needed to determine if that is the case.

A larger sample should also include more English-dominant children or potentially delve deeper into the heterogeneity amongst DLLs. English-dominant children only comprised 20% of the sample in this study. Future studies may also take a more nuanced perspective of DLLs and examine not only the role of language dominance but that of balance, as prior studies have implicated it as a key factor in DLL children's cognitive development [17,18].

Future studies should also examine how these results might extend to other groups of DLL or multilingual learning children. While in the US, Spanish–English DLLs are the most populous group of DLLs, there are many other DLL children nationally and globally. The findings of this study could extend to other DLL children who are exposed to a mainstream language and a home language, where it may be important to screen DLL children for their stronger language prior to administering a science assessment. Results from this study could also extend to DLLs who are learning two languages that are similar (e.g., English and French). However, future research is needed to determine if findings apply in other contexts.

Additionally, it may be important to incorporate classrooms that speak primarily Spanish or English to better understand how teacher talk influences children's learning and performance on assessments. While teachers in this sample reported speaking a mix of English and Spanish, 82% reported that Spanish was their primary language. These results may therefore generalize to Head Start sites that employ teachers who have strong Spanish skills. However, one limitation is that they may not generalize to classrooms where teachers are less proficient in Spanish.

In addition, some teachers may more regularly engage in early science experiences with children in their classrooms. This may have led to differences in levels of teachers' comfort in carrying out science lessons or differences in knowledge about early science. Moving forward, it is critical that studies collect more information about teachers' own comfort with early science and the frequency in which they teach it.

Furthermore, there is a need for a longitudinal study to investigate children's science scores in English and Spanish over time, to understand how their language grows and develops. This includes examining multiple timepoints for language and science measures, to better understand DLL children's abilities at the beginning and end of the school year as well as across years. Lastly, there is a need to examine other factors that may influence DLL language development, such as children's home language environment and exposure to science at home.

5. Conclusions

Engaging young children in scientific inquiry early on provides them with the opportunity to build critical thinking skills necessary to secure one of the growing numbers of science careers in the future [2]. Recently, there has been a national focus on the importance of promoting science in early childhood education. Although science has recently been brought to the forefront in early education, there are science achievement gaps that begin early and persist over time for Hispanic DLL children and children from under-resourced homes [15]. Research with children from under-resourced homes in other school readiness domains highlights the importance of investigating and intervening at an early age [84–86]. The current study contributes to the literature by implicating dominant language as an important factor when assessing Spanish-English DLL Head Start children in classrooms where a mix of Spanish and English occurs. This study also found associations between teachers' use of academic science Spanish and children's English science outcomes, findings which indicate that children's English science scores may be impacted more by teacher language than DLL children's Spanish science scores. This demonstrates a need to account for classroom language use when assessing DLLs. Finally, this study did not find positive associations between academic science language and children's science scores, indicating that classroom quality or quality of a science lesson may be necessary to detect these effects in the future.

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

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education sciences

Article

Deepening Our Knowledge about Sustainability Education in the Early Years: Lessons from a Water Project

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Abstract: The transformative agenda of sustainability education constitutes the focus of early-years education. In quality sustainability educational projects, children are supported to draw links between nature and society and relate to the studied phenomena. Is this methodological approach realized in educational programs for the early years? The present work presents some of the significant findings of a case study on implementing a water project in early-year settings around Europe. It explores the characteristics and the methodological approaches the project implementation developed. Three types of implementation are derived from the qualitative analysis of data and reveal that there are still cases in which sustainability projects are focused on a descriptive approach rather than critical inquiry and analysis. In this sense, the need for educational designs that help children deepen their understanding of sustainability issues and become empowered citizens who will work for a sustainable future is highlighted.

Keywords: early childhood; sustainable development; science education

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1. Introduction

The goal of early childhood science education should be "to develop each child's innate curiosity about the world; to broaden each child's procedural and thinking skills for investigating the world, solving problems, and making decisions; and to increase each child's knowledge of the natural world" [1] (p. 45). The classification of the different trends (empirical, Piagetian, socio-cognitive, socio-cultural) presented by Ravanis [2] underscores establishing a distinct area of research and application that creates a break in the long tradition of Early Childhood Education and the relatively shorter one of Science Education. O'Connor, Fragkiadaki, Fleer, and Rai [3] illustrated that the empirical research on science concept formation in the early years had focused primarily on children aged three to six years. For Kambouri-Danos, Ravanis, Jameau, and Boilevin [4], the precursor model, which children construct, allows them to describe, predict, and explain the state of water changes in a way that is following the scientifically accepted explanation. However, Kallery, Psillos, and Tselfes [5] raised concerns about the quality of science experiences to which young children have access. It seems that a pervasive early-years strategy is frequently to have children seated around the adult while listening to a story being read. Nevertheless, is this an appropriate strategy for Education for Sustainability?

The Importance of Education for Sustainable Development

The United Nations raised the importance of Education for Sustainability in 2005, with a paradigm shift that aimed at drawing educators' attention to a transformative agenda. The primary vision for education was set to change people's minds for a sustainable future. For the early years, this created "holistic images of young children as active participants and decision-makers in their socio-cultural systems with competencies to act for the environment" [6] (p. 1). Education provided children opportunities to experience belonging with nature and develop an awareness of the complex interdependence between all the living and non-living beings in nature. Ultimately this would lead to empowered citizens who would actively work for a sustainable future (Elliott, 2012; Sterling, 2003). This is still very much a target today: the new roadmap for Education for Sustainable Development (ESD) of UNESCO [7] states clearly that the expectation is "the big transformation that is needed for sustainable development" (p. 18). The emphasis is put on teacher education and on building the capacities of educators to deliver ESD.

"Educators remain key actors in facilitating learners' transition to sustainable ways of life, in an age where information is available everywhere, and their role is undergoing great change. Educators in all educational settings can help learners understand the complex choices that sustainable development requires and motivate them to transform themselves and society" [7] (p. 30).

Researchers and educators focused on the methodological elements that can raise sustainability programs' quality, especially those engaging young children [8–12].

2. The Context of the Present Study

In the present study, we present a critical understanding we developed through a water project implemented in early year's educational settings in Europe: Kindergartens, Nurseries, and Day-Care Centers from seven European countries (Greece, Cyprus, Bulgaria, Bosnia and Herzegovina, Croatia, Poland, Iceland) (See Table 1).

Table 1. The number of Early Childhood Institutions that implemented the project.

Type of Institution	Number of Classes
Kindergartens (children aged 5–6)	37
Nurseries (children aged 4–5)	10
Day-Care Centers (children aged 3–4)	2
Total	49

We designed the project to prompt children to explore the relationship between water and human technological culture. Our purpose was to encourage teachers/educators (the terms teacher and educator are used in this study interchangeably) to support children's explorations through an inquiry-based approach. The scope was to take advantage of a "fabric" of scientific tools and ideas (e.g., we would encourage children to carry out observations and record their findings, make measurements, and compare their data). A total of 98 early-year educators in 49 classes (with class enrolling 10–20 children) implemented the program after receiving written implementation instructions. The instructions covered the main scope and the fundamental learning principles of the project and a few ideas about activities. There were also advisory tips that highlighted critical points and the most critical elements of the learning process, where educators focused their attention. No further training was provided to the educators, but they were encouraged to communicate with the researchers if they needed further explanations or clarifications. Written instructions put particular emphasis on the process of inquiry and delineated four main phases (see Figure 1):

- The phase of general preparation: Children were to be introduced to tools and research methods (measuring, observing, recording).
- The preparation of fieldwork (pre-fieldwork phase): Children were encouraged to detect a source of fresh water nearby and plan a field trip.
- The fieldwork phase: Children would have been encouraged to search, look, feel, and record findings.
- The data analysis phase (post-fieldwork phase), which followed fieldwork, emphasized that the four stages should be connected and interdependent as coherence was considered an essential factor for deeper learning. Children would have been encouraged to review information (data) collected during fieldwork to answer questions posed during the previous phases. They would also be encouraged to use multimodal

ways to present their findings (which included artistic and scientific manners of action such as models or graphs).

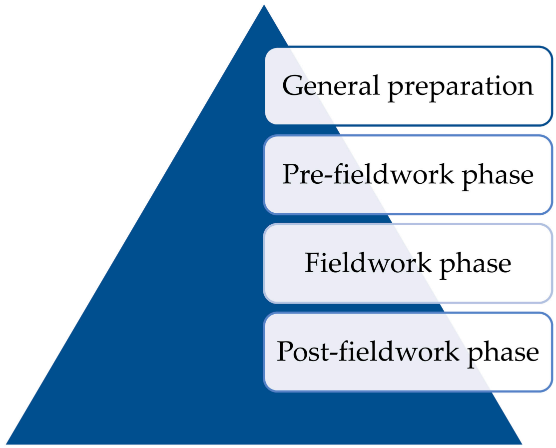

Figure 1. The four main phases.

We provided institutions with the freedom to organize the project at their own pace and time, according to their interests and needs, so each implementation could last from four or six weeks to four or six months if activities were spread over a more extended period. We aimed to embed water education into the broader frame of science education and inquiry-based learning. Most of all, we encouraged institutions and participants to turn their attention to the presence of human activity around the sources of freshwater and the need to protect the riparian zones, the life, and the benefits they accommodate. Teachers supported this through provocative and open-ended questions and the expression of thinking and feeling using multimodal and artistic work. For this reason, we also prompted the project participants (educators and children) to pursue expression through art. That is, to present their findings in a variety of artistic and multimodal ways. ICT was also an integral part of the development of the project. Participants were encouraged to utilize technology in every possible way: as a source of information and knowledge (through the use of the internet, DVDs, CDs, and other digital resources), as a tool of exploration (through the use of digital equipment), or as a facilitator of expression (through the use of technology for the presentation and communication of findings, or multimodal and artistic work). Due to the widespread use of Information and Communication Technologies (ICTs), various technological tools and services have found application in education [13,14]. Thus, we could not overlook that technology, and various applications could be used for environmental education and sustainable development [15].

2.1. Data Collection

The primary tool of data collection was the teacher's portfolio contain all, or some, of the following pieces of evidence (see Figure 2):

- The educators' log, a particular form prepared by the research team, contained open-ended questions that prompted participants to provide basic details about the activities they organized, time length, and essential outcomes of these activities.
- Copies of children's work
- Digital material in the form of selective recordings, photographs, or videos, representing children's achievements.
- Supplementary material used within the context of this project.

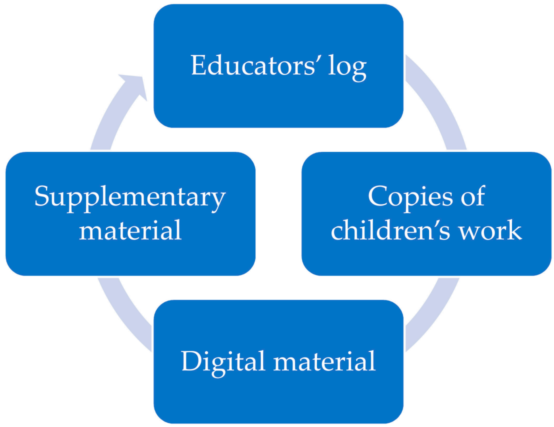

Figure 2. The four pieces of evidence.

The portfolio was chosen among other data collection tools for its "heightened sensitivity to the complexities of teaching and classroom dynamics" as well as for the "ongoing reflection" it instigates and "the expression of virtues developed through documenting a narrative that has intelligibility, […] and communicative power" [16] (p. 110). It is believed that portfolios can go beyond mere reporting and reveal one's teachers' thinking, depending on the degree of insight and reflection teachers are engaged with when compiling the portfolio content [16]. The participants' logs included in these portfolios are also used in educational research as they have the potential to reveal "interesting accounts of developments" [17] (p. 128). Children's work and pictorial material such as photographs and videos are also used as a form of documentation and are perceived as a way to make children's "views," "understandings," and constructed meanings "more visible" [18] (pp. 1–2). Finally, we included selective recordings of children's interactions during the project's activities as these can also reveal what children learn. Portfolios as a whole enabled us to adopt a "systemic" approach to the evaluation of the project results [19] (p. 165).

2.2. Data Analysis

We analyzed the data coming from the above sources through qualitative analysis, which included the following processes:

a. Open coding [20], in which we tried to detect the following categories of evidence in all data sources:
   - The characteristics of curriculum planning.
   - The period over which activities were organized.
   - The educational resources and tools used during the activities.
   - The methodology of activities and instruction.
   - The nature of learning interactions.
   - Other issues that contributed to or hindered the successful implementation of the project.

Table 2 presents the codes which emerged in each category. The above categories reflect the methodological framework presented in the implementation instructions distributed to educators (e.g., in the methodology of activities, instructions urged educators to prompt children's questions and place them at the center of the inquiry process). This framework guided the coding process in a very general way (providing the general purpose of examining each type of evidence). However, the coding was open, and codes emerged as we read and compared the data to the methodological framework.

Table 2. Codes that emerged during the Open coding process in each category of evidence.

General Category	Codes
The characteristics of curriculum planning and implementation	Number (of activities) Coherence (between learning targets and activities) Concepts (exemplified and analyzed through activities) Ideas (developed through the activities) Stages (through which inquiry developed) Connections (with children's background, environment, and social life)
The period over which activities were organized	Number of months
The educational resources and tools used during the activities.	Books Tools Digital resources Artifacts Art and craft materials
The methodology of activities and instruction	Teacher-led instruction Teacher-initiated exploration Child-initiated exploration Child-led activities
The nature of learning interactions	Teacher's presentations Teacher-directed interaction Children-directed interaction Children's interactions dominated by the teacher Children's interactions without the dominance of the teacher
Other issues that contributed to or hindered the successful implementation of the project	

b. Axial coding [20], in which we tried to organize different groups that displayed similar implementation features. The scope of axial coding was developing a critical-hermeneutic narrative, a description of the project implementation that differed from the participants' account and led to a more thorough and profound understanding of the teaching and learning process [21]. The present work is a study of the events as they were presented to us, the researchers, and it reflects our attempt to "get inside" the teachers' experience "based on their description of it" [21] (p. 54). The portfolios submitted to us revealed how educators and pedagogues had interpreted the aims and methods of the project. They also revealed their understanding of how the project's aims and methods could be best met and implemented in their class.

c. From this point onward, we attempted to develop categories "that are systematically interrelated through statements of relationship to form a theoretical framework that explains" teachers' understandings and practices [20] (p. 22).

Coding was carried out by NVivo 12 Plus, and it followed the following procedure. Each of the three researchers coded independently the portfolios submitted by institutions. At the end of each stage of coding (Open, Axial, stage c), researchers met and compared their analysis. Each point of difference or disagreement was discussed, and a mutually accepted resolution was adopted to reach homogeneity and agreement in the results.

3. Our findings: Distinct Categories of Implementation

At the end of our analysis, three main category types of implementation were formed (Type A, B, and C), each of them displaying particular characteristics.

3.1. The characteristics of Type A

Box 1

Examples of project implementation of this type included many activities, which occurred in a short amount of time. Too many activities seemed to be "squeezed" into the time allocated. Moreover, activities displayed superficial coherence and a somewhat fragmented understanding of the topic. A large amount of encyclopedic knowledge was offered to children via teacher instruction and teacher-led presentations. This body of knowledge was overridden by complex concepts resulting in questionable levels of understanding. Sometimes teachers resorted to animism and anthropomorphism to help children understand complex phenomena, such as those involved in the water cycle. Fieldwork appeared to have a minor or peripheral role in comparison to structured classroom activities. There were also scarce opportunities for the children to engage in tactile and hands-on experiences. Their movements seemed to be highly controlled by adults in the name of their safety. There was no evidence that links were drawn between the preparatory stage, the fieldwork, and the post-fieldwork phase, and there was no mention of reflection and further study on the fieldwork findings. Fieldwork seemed to be more of an outing, a quick tour to places of interest rather than a site exploration with persistent observation and careful recordings. Children's engagement with artistic work heavily relied on the teacher's instructions, and there was no evidence that artwork was a means of the learners' sensemaking.

3.1.1. Examples of Projects Displaying the Type A Characteristics:

Example 1. *During the preparatory phase, children were given historical information such as the etymology of the word "water," the importance of water in ancient times, and ancient myths about water. They were also given presentations on the following matters: the importance of water for life; forms of water in nature; the water cycle; living organisms found in water; the correct treatment and use of water; the usefulness of water for households; how water can be transferred from one place to another; the use of water in religion; water as a topic in folk culture. They were also told fairy tales that include references to water. There was no evidence that children explored the above topics through an inquiry-based learning approach.*

As young as four and five years old, children were expected to look at pie charts, maps, and other graphic depictions to understand that water covers and constitutes the most significant proportion of the planet's surface and the human body. Children were also guided to carry out water measurements using standard units without prior experimentation with nonstandard measurements. Selected children executed some water experiments while their classmates were observing the procedure from a distance. Animism and anthropomorphism were used as a teaching strategy: a water drop was presented as a puppet with a human face, and planet Earth was depicted as a round big white bear.

A nearby river was chosen for fieldwork. Before the visit, children were presented with books, CDs, DVDs, and internet pages with information about the local river. Although children prepared equipment which included a camera, paper and color markers, buckets, and spades, during the visit, according to the teacher's report, children were encouraged to carry out measurements which seemed to be practically unmanageable: e.g., they were prompted to measure the volume of water in the river, the depth of the river, the number of pebbles in and around the riverbanks, the number of trees around the river (which, as the teacher noted, were countless), the anthills, and the rubbish on the riverbanks. In the post-fieldwork discussion, children expressed their impressions relating to various aspects, but there was no deep understanding of children's utterances. They also contained references that did not relate to the experiences they had during the field trip. E.g., In summarizing what they learned during the project, children said: "We got to know about ancient heroes," "we say "no" to the melting of Arctic ice, we say "no" to the "Earth's fever," "we learned about the animals of water."

Craft activities were paper constructions that were cut out of the same temple and used the same colors so that every child creates the same product. Crafts seemed to vaguely relate to the subject of water as they included penguins, white bears, and snowmen.

Example 2. *In another Nursery, children aged four were engaged in the following activities: In the preparatory phase, children played and experimented with snow and searched for invertebrates in the school playground after the rain or after the snow had melted. They looked at compound* *words in which the word "water" was the first part-word. They carried out some experiments by freezing water into the freezer and then melting it into the water again. Children were also given a presentation of a variety of paintings that had a reference to water. However, some of these paintings had puzzling symbolism carried: one of the paintings, for example, was "Golconda" by Magritte. Through this, Magritte wanted to pose questions about the connection between individuality and grouping. The teacher asked children to observe the paintings carefully and then answer questions such as: "what is the color of the water on this painting, why is this so, where can we fund water, what is the usefulness of water." No further artmaking (as reflective work on the paintings) was reported.*

Next, children experimented to discover the properties of water, e.g., that water is transparent and colorless, odorless, and tasteless, or that it is a liquid and takes the shape of its container. In a visit to their local public library, children were encouraged to discover fiction and non-fiction books on the topic of water and had stories that contained references to water read to them. For example, one of the stories that struck children's interest was the story of Alcyone. Back in the classroom, children were presented with information about the water cycle which was afterward dramatized under the teacher's guidance and supervision.

The daily fieldwork was reduced to an outing including a "water museum" visit, a dam, and its reservoir. In the museum, children came across tools used by the company that constructed the dam they were about to visit. These included all sorts of objects such as the typewriters and phones of the company administration office. No recordings were reported, and no focused exploration was carried out during the day. A second outing was later organized at a local creek in which some random and opportunistic observations of fauna and flora had occurred.

In the phase that followed their trip, children discussed the consequences of water shortage and tried to construct a small dam and its reservoir using rocks in their playground. As extension work, children were involved in the following activities: (a) themed collages which illustrated metaphors that use the word "water," (b) egg dying, (c) a UNICEF contest about children's rights, (d) a project on water conservation and, (e) drama work on the Greek epic poem of Odyssey.

3.1.2. Why This is not the Preferable Way to Organize Sustainability Projects

The serial presentation of loosely connected pieces of information makes learning problematic, especially for preschool-age children. For the sake of apprehension, pieces of information need to be presented "as an integrated whole with recognition of the relationship between parts" [22] (p. 8). The progressive work on the main ideas can be summarized in each part and then reviewed since repetition and reviewing are proved to support learning achievement. Drawing analogies and using models is essential to teaching because they can enhance clarity and facilitate learning [22]. Moreover, linking new information to what is already known and putting this into action is vital for young children [23]. It is also essential that information put into context and, if possible, becomes *"personally relevant"* or meaningful to children [24] (p. 136) [23,25]. Coherence and connecting links between mental models and concepts seem crucial for quality learning and necessary for challenging young children's naïve beliefs [23,25]. This needs careful planning and ongoing work on interlocking concepts instead of a random accumulation of information.

Providing choice and the opportunity to contribute ideas are also essential strategies that make a project meaningful to children and help in sustaining motivation. A *"need-to-know"* approach can meet the condition of the *"student input"* [25] (p. 68) [23]. Allowing children to enter the *"flow"* state is essential and can only be facilitated if there is no rush and activities are spread comfortably into time (Helm and Katz, 2001). Moreover, apprenticeship is vital for new skills. Therefore, it should be carefully planned and organized [23]. In our project, the introductory phase was supposed to resume and bring up the vital role of apprenticeship to help children claim new skills to use at later stages. Rushing through or overloading the introductory phase with various information and activities jeopardized the primary role of this phase. Thus, the provision of large amounts of information, which is somewhat fragmented and disconnected from context, or bares loose ties with a central topic, and outside children's experience or delivered in a short amount of time, does not qualify as a suitable teaching and learning approach.

Anthropomorphism is how teachers assign human characteristics to non-human beings and things [26]. Research reported by Kallery and Psillos [27] shows that Greek teachers tend to use anthropomorphism to help children access and understand complex concepts and connect their experiences with unfamiliar phenomena and elements. However, the debate has grown about whether or not the anthropomorphic speaking methods should be used in the classroom [28,29], primarily if they are modeled by the teacher [26,29]. Although children do not always appear to copy the anthropomorphic thinking of their teachers uncritically, they seem to align with their way of speaking generally.

Researchers, therefore, bring this issue into question for three main reasons:

(a) When it comes to science education, this type of conversation might hinder knowledge acquisition [26].
(b) Research on where anthropomorphism facilitates better understanding in young children and where not is scarce and inconclusive. Instead, it is argued that personification yields the danger of "unreasonable personifying responses" [27] (p. 308).
(c) Research also identified the need for young children to focus on the natural causes. Causal explanations of natural phenomena transition from their early animistic or artificialist way of thinking to a deeper understanding of the physical causality in the natural world [30].

In our project, some teachers used stories and poems in which water drops had human features (such as smiling faces), a gender (either male or female), emotions, and were able to think or relate like humans (had parents or siblings). They reported using this type of literature as core texts unquestionably and without hesitation. They even created puppets to enact narrative and encouraged children to draw these drops and elements such as the clouds or the Sun depicting human features.

The promotion of the sustainability goals does include spiritual elements and a dimension of animism, to the extent that we perceive planet Earth as a *"precious"* and *"sensitive"* ecosystem which is *"alive," "interdependent,"* and in a state of continual *"becoming"* [31,32]. However, this is not ascribing sentience to inanimate things as teachers do. *"In this strong animism, bonds of mutual life-giving subtend relationships among individuals and groups, across species; they include a great range of beings, even some landforms"* [33] (p. 496). Good practices introduce children to this *"ecological ontology"* by focusing on *"connectivities, continuities, and responsibilities"* [33] (p. 496) [34]. Storytelling and animism of the traditional stories can also be introduced to children as a sample of a *"different knowledge system"* [35] (p. 13), and this needs careful planning to avoid giving children false impressions.

We also need to discuss the issue of children's art and craft activities. Children's artmaking provides documentation of "cognitive and imaginative ways of knowing" [36] (p. x). Through art, children display their thinking, what they know, how they feel, and what they prefer [37]. Encouraging children to take up "risk and challenge" is essential to creativity [38] (p. 33). Furthermore, this cannot be achieved through controlled, uniform, and teacher-directed art and craft making. Children should be encouraged to respond freely to materials and feel that peers and adults respect this work. It is argued that, especially for young children, artmaking should be based on children's responses instead of being organized as a series of activities with predetermined end-product in mind (Brook, 2003). In strictly organized activities, children end up more "acted upon, rather than being active participants in artistic processes" [39] (p. 12).

3.2. The Characteristics of Type B

Box 2

In this type of implementation, the stages of the project were distinct and well developed. They contained a reasonable number of well-connected activities that led the project from one stage to the other with coherence. The content was straightforward to permit the process to develop in complexity. The children were taken to water sources and encouraged to observe, explore, play and record their findings or collect small objects as evidence and further study in the classroom. Investigations included consistent planning and inquiries [40]. Preparation also included the definition of concepts, familiarization with tools, measurements, and recordings. Children were encouraged to ask questions, and their questions were placed on a central stage during the inquiry. Interviews complemented fieldwork, and exploration expanded through various sources that included books, digital resources, and people. Throughout the process, teachers supported children in collecting and interpreting data, sometimes using mathematical thinking to help children elevate their levels of understanding. Through procedures that resemble scientific and well-documented inquiry, educators supported their children to construct explanations [40]. The project was successfully drawn to conclusions and an exhibition of findings. Alternative expression means were explored, such as 3D constructions with recycled material and or drama play.

3.2.1. Examples of Projects Displaying the Type B Characteristics

Example 1. *Children's interest was ignited through a couple of discussions: teachers recorded children's questions on a big poster and used them as a point of reference throughout the length of the project. Preliminary work with tools and measurements evolved around a simple question that emerged during free play: "How big are the puddles in the playground?" Children were encouraged to carry out measurements using nonstandard and standard units (e.g., they measured the width and the depth of the puddles) and compare measurements recorded at different times of the day to study the effects of rain in the playground. A gap in children's experience was identified from interactions with migrant staff: water shortages experienced in other countries of the world were less familiar to them since they lived in a place with plenty of water in the environment. A second mini-investigation was organized in which the class measured and recorded the water consumption at lunchtime in the kindergarten. Children in the fieldwork were encouraged to spot the nearest neighbor map (an ocean coast and a tiny island). Before the outing, they were also encouraged to form hypotheses (animals and earth elements they expected to find there), to decide about the equipment they needed to take with them (containers for collections, wool socks, buckets, magnifying glasses, cameras, iPad, fishing nets, etc.) and the mode of transportation. It was evident that children were the decision-makers in these processes and made several proposals based on their living experience. Fieldwork was repeated twice at different times of the year and allowed children to compare the differences in the environment (the first time everything was covered in snow, and the second spring was all around). Children were thrilled to discover elements hidden under the snow during the first visit, observe the colors and the riparian zone, and collected samples for further study in their classroom. In their post-fieldwork discussions, children were supported to classify the elements they discovered according to two criteria: (a) they separated plants from animals, and (b) they formed different groups of seaweeds according to size and color. Artmaking focused on children's idea to "paint the water." Children were given a choice to make their painting on pieces of cloth and decorate it with any materials and any manner they wanted. Individual pieces were sewn together to form a big patchwork sheet.*

Example 2. *Children started their project by watching a film about the importance of water for Earth. Several activities during the preparatory phase led children to realize and take notice of phenomena related to water and their impact on nature (absorption, flow, floatation, permeability, water saltiness, water pressure). They observed experiments in which leaves absorbed color or were left to dry in an empty glass. Many measurements with nonstandard and standard units enabled children to familiarize themselves with observation, measurement, and recording procedures and helped them develop a good sense of volume. Looking at pictures, children noticed that animals and plants live near sources of water. Thus, they interviewed a zoologist and a local fisherman to get more information about life in and around water sources. The zoologist tried to explain how* *the food chain works, and the fisherman concentrated on the importance of keeping water clean to enable healthy fish to grow. Water pollution then came into focus, and children experimented with filtering dirty water. With support, children sought to find sources of fresh water in their local area. They realized that there was a river with a marsh nearby and prepared an outing. Preparation included care for suitable vesture and necessary equipment such as magnifying glasses, meter, nets, boxes for collections, pond scope, binoculars, etc. It also included rules like "keep the noise and water disturbance to a minimum, or else small animals, fish, and invertebrates will be scared away." Children also looked at tourist guides about the places they were going to visit.*

The excursion included three significant stops: the river spring, the marsh, and the river delta. During the outing, children made observational drawings that depicted the colors of the environment, animals, and plants they saw, even the sounds they heard on the site. They measured the water temperature using nonstandard (by dipping their hands in it) and standard units with support (a proper thermometer) to realize that the water was colder at the river spring and warmer at the marsh or river delta. At the three stops, they tasted the water and noticed that saltness was felt near the delta, concluding that this was coming from the sea.

In the post-fieldwork phase, children discussed their findings. The discussion revealed that they had developed a good understanding of how water supports life and the growth of entire ecosystems. They also developed an excellent understanding of the purpose of their exploration and identified the need for environmental cleanliness and health as the most important thing they learned from their inquiry.

3.2.2. Why is This Important

Good quality sustainability programs develop learning sequences in which children are encouraged to search for answers to their questions and try to "explain what they observe." They also prompt children to use what they know "in reasoning about what they observe," and they share the belief that "struggling is critical to learning, just as it is a critical part of the way science is done" [40] (p. 12) (see also [41]).

Fieldwork is an essential part of experiential learning, especially in urban settings in which children have limited access to the flora and fauna of their geographical area. Limited experiences of the natural environment make it difficult for children to develop a sense of connection to nature, to build their experiential knowledge, and develop sensory awareness of their place in the ecosystem [41,42]. Mental activity is not downgraded but is used to help children link and apply new and abstract knowledge to the real world (materials, facts, and actions) [24].

Developing scientific literacy about water is expected to contribute to the development of a "water ecoculture" and help us understand the importance of water as a constituent of life and as an agent of culture. Therefore, good sustainability projects allow children to study the contribution of water in biological and social life using crosscutting scientific concepts. For example, teachers may encourage children to make recordings of water usage or consumption on several occasions, in and out of school. Apart from teaching children how to carry out measurements, these recordings enable children to observe patterns in water use, human behavior, and the factors that influence them (e.g., water leakage, water consumption rises, accruing environmental damage, and financial costs). In quality projects, teachers need to encourage children to pursue further inquiry, seek answers to their questions, gain some basic understanding of the relationship of cause and effect, and expand their inquiry at multiple levels in increasing depth and sophistication.

Finally, art activities that engage young children with debates add an emotional dimension to the learning process and are particularly important for sustainability education. This is because an appeal to people's rational cognition cannot always persuade people to change their behavior or become proactive, and sustainability as a cultural tool might be difficult to grasp [43].

3.3. The Characteristics of Type C

Box 3

Type C displayed all the characteristics of Type B (in a few words: simplicity, coherence, connections, emphasis on children's questions, strong congruence with scientific inquiry, multimodal ways of presenting findings). Moreover, projects of type C went a step ahead in that they connected children's learning to their backgrounds, their social environment and pursued deeper investigations into the subject of water as an element in human culture.
Educators offered children opportunities to explore problems with their social dimensions [40]. This enabled children to draw meaningful, mutually consistent relationships between pieces of knowledge or information and yielded richer project results. Teachers also encouraged children to use models (and sometimes to develop models themselves) to understand and find answers or solutions [40].
Teachers enabled children to engage in arguments and hear contradictory views and aspects [40]. Apart from fieldwork, the inquiry processes included interviews of multiple agents (local community members, scientists, engineers, etc.) who could elaborate on different aspects of the main issue. During the interviews, people's personal stories and well-being were examined and paralleled to scientific judgments and technological achievements. Personal interests were compared to the common good and personal views intertwined with professional judgment and integrity. Cross-examination led to a countercheck of the individual to the collective and the subjective to the scientific. In this, children were also encouraged to discuss their concerns.
As teachers supported children to obtain, evaluate and communicate information in various multimodal ways [40], projects made extended use of the possibilities offered by ICT and technology.

3.3.1. Examples of Projects Displaying the Type C Characteristics

Example 1. *Through guided inquiry, children studied the case of a local dam. They sought to find the need and purpose of this water management project, details about its construction, and details about the wetland features that develop in and around the reservoir. Children were prepared by monitoring and recording water consumption at school and home, looking at and analyzing water bills, and publications about water shortage. During a physical visit to the dam, they discovered a hamlet located inside the dam reservoir, which had to be abandoned. This hamlet sinks and re-emerges each year following the fluctuations of the water level in the reservoir. Children were thrilled by this discovery and asked to learn more about the sunk hamlet. Teachers then organized interviews with locals, as well as engineers from the treatment plant. Children discovered that local communities were strongly opposed to constructing the dam despite their compensation for expropriation. Older people refused to abandon the hamlet until the very last minute, just before the water level flooded their properties. Children heard contradictory arguments which interviewees carefully phrased using simple language and realized that public interest and the overwhelming need for drinking water prevailed. The dam was set to serve a population of 300,000 inhabitants. Artmaking supported every phase of the exploration to enable children to express their emotions, culminating impressions, and ideas. E.g., children made collective works of "land art" on-site when they visited the dam banks for field study. A group of children chose to make a colorful heart on the ground to express their sorrow for the abandonment and immersion of the hamlet.*

Example 2. *On another occasion, children explored the local coastline and discovered the underwater ruins of a sunken city. Children's interest sparked, and a series of interviews with locals led children to discover that this was the outcome of an ancient earthquake of great magnitude. Children asked to learn more about earthquakes, which developed a whole new twist to the water project. A new inquiry pathway emerged that enabled children to learn about earth plate movements, rifts, and their impacts on the landscape. Discussing the fate of ancient survivors who immigrated and rebuilt their communities in other locations of the same geographical area, children were encouraged to consider issues of immigration and displacement. At the culmination of their project, children linked their discoveries to issues of migration and refuge as experienced in their society (this was during a period that large numbers of migrants and refugees were crossing the Mediterranean to arrive in Italy, Greece, Spain, Cyprus, and Malta).*

3.3.2. Why Is This Important

Making inquiry meaningful and personally relevant elevates children's interest in a topic and contributes to a more profound understanding [24]. Science contributes in a unique way to the development of culture. Science has contributed to the development of values, ideas, and our worldview. Sciences contribute to and deepen our understanding of the world, and, thus, they are part of a "liberal education" [44]. To develop an understanding of the nature of science, educators probably need to act as cultural mediators [45]. Through engagement in the critique of scientific values and ideas, or explorations of contradictory views, and the impact of scientific projects in society, children are actively involved in developing culture. Reflection processes are also involved and help students derive knowledge from experience [41,46].

Embracing their local history and or ancestry is also an essential factor contributing positively to students' emotional connection with their physical environment [42]. The collection of oral stories and local inquiry into the lived experience of people help children to attach these stories to their own. This also increases the sense of attachment to places and the development of "a narrative about their own lives that is meaningful and focused on living in ways that support the welfare of others" [42] (p. 94).

3.4. The Classification in Numbers

Table 3 presents the number of classes classified in each Type (A, B, or C) according to the characteristics displayed in their implementation of the project.

Table 3. The number of classes in each type of implementation.

Type of Implementation	Number of Classes
Type A	24
Type B	21
Type C	4
Total	49

As Table 3 shows, most classes displayed characteristics that classify them as Type A in our classification. Type B follows, and only a minority of four classes displayed the Type C characteristics. The prevalence of Type A implementation is a matter of concern seeking further investigation and additional research. This goes beyond the scope of the present study, which is set to present, classify and discuss the different characteristics classroom implementations have developed.

4. Discussion

Successful sustainability projects helped children to draw links between nature and society and relate to the phenomena they studied. We can distinguish two major approaches to ESD that link to different paradigms: One that adopts a mainly "descriptive approach aiming at behavioral modification" and aims at a "democratic, participatory empowerment." The latter sets out to educate active citizens who will pursue democratic activities on sustainability [47] (p. 40) (See also, [48]). It is a request for "transformative action" according to UNESCO (see also [49]), and as such, it demands the following advances: "Disruption," which is necessary at first, to make people break their usual way of thinking, feeling, and acting. Critical reflection and insight are also pivotal for people to break their habits and exit their "comfort zone." When it comes to transformation, it seems that there are two pathways. It can either lead to the technical knowledge of how things happen or "to a deeper connection with the issues." The cultivation of empathy results from education processes that relate to compassion and relevance to one's own life, which means that learning must be realized through critical inquiry and analysis, exposure to different viewpoints, arguments [50] and debates, and empowerment to take action. Links between learning and social participation need to be drawn [7] (p. 57) [51]. "Multiple representations of content" and "multiple options for expression and control" [51] (p. 32) are needed as well as space and time for experimentation with new or "disruptive" ideas to enable children to become active and transformative learners [7] (p. 57).

One of the most fundamental defining characteristics of effective Environmental Education is the need for the subjects or objects of an inquiry or an activity to be approached with the help of all sciences at the level of school knowledge and practice [52–55]. A mobile learning perspective can enhance this approach. For instance, the combined use of smart mobile devices and QR codes could be used as a bridge between offline and online content, connecting physical objects with information related to the internet and access to multiple communication channels. This perspective has a strong potential for enhancing inquiry-based learning and the development of transformative action. In recent years, the development of mobile devices has profoundly shaped the landscape of mobile learning by changing its features and characteristics. Mobile learning is now provided through small, lightweight, reliable, and surprisingly powerful devices with internet connectivity and an impressive number of easy-to-use software applications (apps) made exclusively for a mobile device.

Given the abovementioned characteristics of mobile learning with technological tools such as the QR codes, mobile learning can link formal and informal learning and mobile technologies in environmental education programs, making learning happen anytime and anywhere [56]. Moreover, mobile technology can provide more options for the "multiple representations of content" and the "multiple options for expression and control" highlighted by Kershner [51] (p. 32). Further exploration and research are needed on the ways technology, ICT, and mobile devices can empower learners and become the tools of effective sustainability education [57] and deeply investigate the arguments advanced by young children during a problem-solving situation [58].

5. Limitations

The present study highlights and analyzes some of the most outstanding issues while implementing a water project in early childhood settings in Europe. The sampling was convenient and by no means representative of the population, so this article can only be a case study. The above findings are not conclusive and cannot be considered indicative of the practices realized in each country that participated in our project. Research of a grander scale is needed for safer conclusions regarding the standard practices in ESD for the early years in European Countries. However, our analysis brings up issues worth considering, especially regarding educators' potential to support teaching and learning for empowerment, equity, and sustainability.

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Review

Starting at Home: What Does the Literature Indicate about Parental Involvement in Early Childhood STEM Education?

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Abstract: Developing STEM (Science, Technology, Engineering, Mathematics) competencies is a global priority. In response to this educational need, initiatives have been implemented mainly at the school level. However, in preschool education, the STEAM programs are more recent. Research advances orient preschool teachers to reach these competencies in school-based programs, although parental involvement has been systematically forgotten as a critical factor. This article describes the current issues on research about parental participation in STEM education in early childhood to identify advances and gaps. We selected documents published between 1995 and 2021 in the leading educational databases, identifying 11 documents explicitly related to parental involvement in STEM education in preschoolers. The results show that STEM activities can promote parental engagement, improve the value parent attribute to STEM, and positively affect STEM learning in preschoolers. Moreover, parents shape children's interests and self-efficacy about STEM and content application that can favor their children's approach to STEM. This article discusses the scarcity of research published on the connection between STEM and parental influence, despite the fundamental role of parents in early STEM education. We present practical criteria to guide the development of early STEM education in the family context and questions to guide the planning of research and intervention programs.

Keywords: STEM; STEAM; science education; early childhood; preschools; parental involvement; engagement

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1. Introduction

Parental involvement in children's education (the use of the terms "parental", "fathers", or "mothers" is not limited to biological fathers, but includes any adult who assumes a role of caring for a child (e.g., grandparents, legal guardian, etc.) can create a virtuous circle that helps cope with the world's technological, environmental, and social changes [1]. When parents participate in the early construction of STEM competencies in a relevant and familiar context for children [2], this constitutes an engine which drives a more equitable and sustainable society [1,3].

Exploring what the literature reveals about parental involvement in STEM education in preschoolers is worthy, considering the relevance of parental involvement and its possible effects on academic outcomes, processes, and psychological characteristics such as self-efficacy, self-regulation, and motivation [4,5]. Two reasons sustain this assertion: parental participation is an innovative research field with the potential for high-stake program implementation decisions [6] and early childhood systemic interventions has a well-known positive cost/effectiveness [7].

1.1. STEM Education

Technological changes are transforming all areas. Indeed, education has been one of the sectors in which technology has moved the boundaries of status quo practices.

The interest in STEM education (science, technology, engineering, mathematics) has increased during the last decades; highlighting the need to develop skills associated with these disciplines [8,9], such as problem-solving, critical thinking, inductive and deductive reasoning, goal setting, decision making [10–12].

Added to this is the impact that the shortage of people in these disciplines generates on nations and individuals, and the role STEM disciplines have in achieving sustainable development goals [3]. The 17 goals in the 2030 Agenda on Sustainable Development approved by the United Nations in 2015 seek to eradicate poverty, combat climate change, improve education, and promote gender equality [3,13].

Thus, STEM skills have been prioritized internationally [8,10,14,15]. Practical actions have advanced policies and programs to provide infrastructure and technological resources, teacher training, communication campaigns, and educational material [16]. Nonetheless, promoting family involvement and informal learning at home has been suggested but less implemented [14,17,18].

There is currently no agreed-upon definition of STEM literacy. However, there are common points: (a) the importance of addressing real and contextualized problems so that the concepts are relevant at a societal and cultural level, (b) the need to promote the integration of STEM disciplines within programs and activities, as they share concepts and practices allowing students to apply their knowledge and skills, make connections, gain an understanding of concepts, and solve complex problems [2].

Although there is agreement among researchers about the importance of integrating the different STEM disciplines [2,19,20], two areas of debate are detected: (1) the degree of integration versus the separation between disciplines and (2) the integration of additional disciplines.

For this literature review, we used the notion of the continuum by Moore et al. (2020) [2]. We included articles reporting parent-child involvement in activities ranging from the low integration of STEM disciplines to project- or problem-based learning with a greater integration of disciplines. Additionally, incorporating other fields into STEM is considered in the current study, such as visual and plastic arts, including the A into the acronym STEAM [2,21–23]. We include the arts because it helps contextualize problems, favor children's learning, and promote their creativity, communication, and teamwork [2]. It brings science closer to those who have not had contact with it, making it more familiar and accessible [24].

1.2. STEM Education, Preschoolers, and Parent Engagement

The early exposure of children to STEM areas is feasible and would positively impact their learning. This is due to their innate curiosity and creativity and their willingness to analyze, hypothesize, and predict. Hence, children could feel motivated by concepts related to these disciplines, facilitating their learning [25].

Preschoolers can already conceptualize and create mental representations of natural phenomena, which is the basis for acquiring new and more complex learning [26]. Because of this, STEM concepts and skills developed at an early age would allow children to explore and understand more complex concepts in the school period [25,27]. Moreover, if these concepts are socially and culturally relevant, children perceive the impact of STEM in their lives and the opportunities to pursue a career in these fields [2].

Despite this enormous potential to promote learning and open career opportunities, early childhood classrooms have shown some reluctance to include STEM content in a meaningful way [27,28], with some exceptions such as the incorporation of engineering design challenges, which allow for the integration of science and mathematics knowledge, to solve real problems [29]. A few studies link early childhood with science, technology, engineering, and mathematics [28,30,31]. Thus, there are challenges for program and research implementation, such as examining aspects of STEM education in preschool classrooms (e.g., program design and content and STEM teacher education, among others) and at home [28]. Regarding STEM education at home, parents play a crucial role. Indeed, evaluating the impact of informal scientific opportunities and designing policies that promote STEM teaching in early childhood while allowing caregivers and teachers to merge STEM learning with family experiences is recommended [28]. The inclusion of parents could facilitate adapting everyday life with STEM skills [31].

Parental involvement, inside and outside the school, is recognized as one of the most transcendent factors within children's educational process, given the impact on their academic performance and the psychological processes that contribute to it [4,5]. The definitions of parental involvement are multiple within the literature. For instance, it can be understood as participation in activities carried out in the school (e.g., meetings of parents, walks), decision-making and communication with the school, and participation in educational activities within the home [4]. From this perspective, the involvement of parents in STEM education would favor children's learning, knowledge transfer, content control, exposure, and access to concepts, skills, and tools related to STEM [25].

2. The Objective of the Literature Review

The present review seeks to determine what the literature points out about the involvement of parents in early childhood STEM education in a novel way. STEM education in preschools and integrating these topics with parental involvement are a niche of recent research concern [28,30,31]. The findings of this work may help identify advances for informing the practice of STEM preschool education and guiding future research and programs in this field. It may also promote parental involvement positioning as a relevant source of contextual support for children's integral development.

3. Methods

A scoping review of previous works was used to describe the state of the field and empirically shed light on the area of parental involvement in preschool STEM education. According to the PRISMA framework [32], the scoping review is a broader approach to evidence synthesis when formulating discrete research questions that are premature.

Anticipating that we might find a few empirical studies in the field, we considered theoretical and empirical documents such as articles, books, and book chapters. Moreover, we continued through a snowball sampling to follow seminal papers or authors of interest. The following inclusion criteria for searching in the Web of Science (WoS)) and Scopus databases were used: (a) documents that included in their title, abstract, and keywords (from the author and/or plus), the words: (STEM OR STEAM OR Science education) AND (early childhood OR childhood OR preschool*) AND (parent* involvement OR family involvement). (b) reporting empirical or theoretical studies; (c) publication dates between 1995 and 2021. This search was conducted between June and July 2021. It is important to note that "formal education" and "informal education" or similar concepts were not intentionally included or excluded as search terms in this review. Therefore, the database search results suggested studies focused on parent and child participation in both settings, mainly at home, classroom, and workshops. Other spaces such as museums, zoos, and parks did not appear in these databases using the search terms. We did not search for the terms Science, Technology, Engineering, and Mathematics separately. The exclusion criteria were: (a) conference proceedings (b) documents associated with areas other than education (e.g., medicine).

As shown in Figure 1, the Boolean search resulted in four articles extracted from the Web of Science database and six documents (five papers and one handbook) from the Scopus database. Repeated records were deleted. In addition, the handbook was reviewed thoroughly, but one article only addressed parental involvement in children at a general level. The result obtained was four documents (three papers and one handbook chapter) complemented by snowball sampling. The references section of each document obtained in the databases and texts included in the introductory section of this review were reviewed. Authors who had participated in books that fit the inclusion criteria were also identified.

At this stage, six articles and one book chapter were detected that met the inclusion criteria and were added to the documents selected in the previous step.

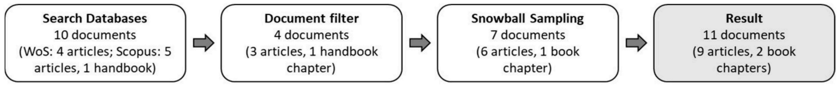

Figure 1. Flowchart of review stages.

The final selection process included 11 documents (nine articles and two book chapters), characterized by considering aspects such as authors, year of publication, origin, topics discussed, and results. The selected articles are detailed in Table 1. Although the search covered the period between 1995 and 2021, the documents that met the inclusion criteria were published between 2004 and 2021, with a concentration of 90.9% between 2017 and 2021.

Table 1. Summary of documents included in the literature review.

N°	Authors	Year	Journal or Book	Country	Discipline (S-T-E-M)	Type of Study (Emp-Theo)	Methodology (Ql, Qt, Mx)	Sample (Tch, P, Ch)	Context	Focus
1	* Ata-Aktürk, & Demircan [33]	2021	Early Childhood Education Journal (A)	Turkey	E	Emp	Qi	2 Tch 5 P 5 Ch (5–6 years old)	Classroom	Test curriculum with emphasis on engineering
2	* Thomas et al. [34]	2020	Handbook of Research on STEM Education (BC)	United States; Turkey	S T E M	Theo				Literature review
3	* Ulutaş & Kanak [35]	2018	NeuroQuantology (A)	Turkey	S	Emp	Qt	60 P 60 Ch (5–6 years old)		Investigate the impact of the parent–child science education program on basic process skills
4	* Ginsburg & Golbeck [36]	2004	Early Childhood Research Quarterly (A)	United States	SM	Theo				Reflect on directions of early teaching of mathematics and science
5	** Strickler-Eppard, Czerniak & Kaderavek [37]	2019	Early Childhood Education Journal (A)	United States	S E	Emp	Mx	5 P 5 Ch (4–8 years old)	Home	Describe how families utilize science activity packs at home
6	** Raynal et al. [38]	2021	Early Childhood Education Journal (A)	United States	S	Emp	Qt	88 P82 Ch (4–8 years old)	Workshop for parents, home	Explore a model designed to support family science
7	** Tippett & Milford [39]	2017	International Journal of Science and Mathematics Education (A)	Canada	S E M	Emp	Mx	2 Tch 11 P 14 Ch (4–5 years old)	Classroom	Evaluate STEM activities in the preschool classroom considering the parental perception
8	** Tay, Salazar & Lee [40]	2018	Journal for the Education of the Gifted (A)	United States	S T E M	Emp	Qi	55 P (parents of PK-K children)	Saturday STEM enrichment program for children	Know parents' perceptions of the influence of STEM programs on preschoolers and their attitudes toward STEM
9	** Gilligan et al. [41]	2020	European Early Childhood Education Research Journal (A)	Ireland; United States	S	Emp	Qt	85 P (parents of children from 4–8 years old)	Workshop for parents	Evaluate parents' attitude towards science
10	** Pattison & Dierking [42]	2019	Science Education (A)	United States	S	Emp	Qi	7 P 7 Ch (4 years old)	Head Start Program	Understand the development of interest in science in children from underserved communities
11	** Ünlü-Çetin, 2020 [43]	2020	Key points for early childhood STEM education and involving parents (BC)	Turkey		Theo				Promote parental involvement in STEM (First deliverable ParentSTEM project)

* Document obtained from database search; ** Document obtained through snowball sampling. A = Article; BC = Book Chapter/S = Science; T = Technology; E = Engineering; M = Mathematics. Emp = Empirical; Theo = Theoretical/Qi = Qualitative; Qt = Quantitative; Mx = Mixed. Tch = Teachers; P = Parents; Ch = Children.

The content of the revised papers was grouped into categories related to the question that we sought to answer through this review: What does the literature point out about parental involvement in early childhood STEM education?

4. Results

Research on parental involvement in early childhood STEM education is recent and still scarce. Most papers included in this review were from the United States (6) and

Turkey (4). Three papers were theoretical, and eight were empirical studies. From the latter, three used quantitative methodology, two used mixed methods, and three used qualitative methods. The samples were mostly parents and their children (aged 4–8 years), and only two studies considered the participation of teachers. Sample sizes ranged from 5 to 88 parents, 5 to 82 children, and 2 teachers. The studies were about interventions and programs focused on the home, classroom, and STEM workshops for parents and children. The number of empirical studies addressing STEM disciplines was science (8), technology (1), engineering (4), mathematics (3). The documents, in general, have been cited little, perhaps due to the recent date of publication of some of them.

The findings support that parental involvement in early childhood STEM education has focused primarily on describing how parents engage in STEM activities and the effect on their children's STEM learning. Furthermore, the research describes the influence of their education or experience on their participation and children's learning, their beliefs and emotions about STEM, and perceptions about STEM programs. Finally, it described the potential of STEM activities to promote parental involvement. These points are presented below:

4.1. Ways in Which Parental Involvement Is Expressed during the Performance of STEM Activities

Parents have differences in expressing their emotions, affection, and interest in their leadership style and how they try to capture their children's attention during STEM activities. For example, during STEM activities, parental involvement is expressed in various ways. Moreover, differences are observed in the way parents interact with their children and express affection, emotions, and interest. Some parents explicitly praise their children, give them continuous feedback, and express their enthusiasm for STEM activities, while others verbalize frustration, impatience, or lack of interest [42]. A similar pattern can be found regarding the leadership that parents assume during STEM activities, ranging from a managerial style—i.e., deciding for their children—to a passive style—giving space for children to choose more frequently and explore more autonomously.

Finally, there are also differences in the strategies parents use to redirect children's attention during STEM activities, ranging from capturing their attention by explaining the activity and allowing greater participation to encourage children to continue the activity or to abandon it and move on to the next one [42].

4.2. Effects of Parental Engagement on STEM Learning

Parental involvement can positively and negatively affect STEM learning in preschoolers. Indeed, parents' engagement with STEM activities might generate satisfaction in children, which would favor their learning [33]. In addition, the participation of parents contributes to increasing the results obtained by children in tests that measure scientific process skills such as observation, classification, comparison, measurement, and communication [35]. Overall, parents are crucial for increasing children's participation in early science [41].

Another positive aspect is the role of parents as providers of resources and stimuli that bring children closer to STEM topics (e.g., computers, books) [36]. Parents can also be role models and sources of help and knowledge [36]. Parental involvement is also a source of educational advantages for children, enhancing quantitative and problem-solving skills [34].

Nonetheless, parental involvement in STEM activities can also be affected by the overly intrusive attitude in the activities, which might impact their children's performance during the activities [33]. Moreover, parents can transmit stereotypes that constitute barriers to learning, such as the idea that STEM is not for young children or nor suitable for girls [43], or even transfer fears about STEM, especially regarding mathematics [36]. Likewise, some parents might put excessive pressure on children to learn a particular subject, which can be counterproductive [36].

Additionally, there is a mediating effect of culture and belonging to certain social groups on parental involvement, which can positively and negatively impact children's

STEM learning [34]. For example, a higher socioeconomic status and ethnicity (e.g., Americans, Japanese) are associated with greater parental involvement in STEM learning [34].

To sum up, all the above shows that parental involvement can have a mixed impact on preschoolers' learning, outcomes, participation, self-efficacy, and beliefs about STEM.

4.3. Effects of Parents' Education or Experience on Their Involvement in STEM Activities and on Their Children's Learning

According to the literature consulted, parents' education and their previous experience in STEM disciplines have a variety of effects. On the one hand, the lack of experience or prior training in science is not a limitation for parents to provide scientific experiences aimed at their children, to the extent that they are provided with activities and good support material to help them in this work [37]. Indeed, without their educational level or experience being an obstacle, parents can conduct STEM activities where their children learn scientific practices, concepts, and processes [37].

On the other hand, a higher level of parents' STEM education does not necessarily translate into an advance in parents' confidence to talk about science and participate in scientific activities with their young children. For instance, in Gilligan et al.'s (2020) study [41], although participants had a high level of education, approximately half felt less confident discussing science and participating in STEM activities with their children, with mothers expressing greater insecurity than fathers. Likewise, the parents' training in a STEM discipline such as engineering is not associated with a greater competence of their children in activities related to this subject [33].

The above findings suggest that a higher level of training and experiences linked to STEM is not necessarily related to parents' greater capacity and security to address STEM issues and activities and higher competences of their children in these disciplines.

4.4. Parents' Beliefs and Emotions about STEM

Parents' beliefs and emotions about these disciplines can be positive or negative, considering their impact on children's STEM learning. On the positive side, parents express interest and enthusiasm toward both STEM activities and learning [38,42], and the belief that science teaching should begin in the preschool stage [41]. On the negative side, parents' lack of interest or impatience experienced during STEM activities with their children has also been reported [42]. Additionally, some parents experience insecurities when talking about science or doing scientific activities with their children [41]. These findings show that parents' beliefs and emotions during STEM activities or related to STEM learning are factors that can facilitate or hinder children's STEM learning.

4.5. Parents' Perception of the STEM Programs in Which They or Their Children Participated

Parents tend to positively perceive STEM programs and activities they or their children are involved in and, in general, they favorably evaluate the STEM classes their children attended [40]. Besides, many parents value the opportunity for their children to participate in STEM programs, perceive STEM disciplines as necessary in their children's education, and think science is practical; to solve the problems of today's world and achieve better results in the work environment [39]. In addition, there is evidence reporting parents' positive perception of the STEM knowledge acquired by their children and the enthusiasm of their children to learn and participate in STEM activities [39,40]. Similarly, parents can detect positive changes in their children's attitudes and behaviors, such as a greater openness to new experiences and learning when participating in STEM activities [40].

While positive perceptions and assessments about STEM activities prevail, parents also raise needs or expectations, such as receiving more information about STEM activities in the classroom, STEM in general, and how they might use STEM in interactions with their children outside the school [39].

The above insights show a general satisfaction and valuing of parents toward STEM activities and the needs and expectations linked to a greater access to STEM information.

4.6. Potential of STEM Activities to Promote Parental Involvement

When designed externally and with the support of diverse actors, such as daycares, schools, universities, museums, zoos, etc., STEM activities can foster parental involvement in science practices by helping parents engage their children in a discourse about scientific concepts and processes [37]. Moreover, STEM activities can foster enthusiasm for solving problems collaboratively between parents and children [38], as well as the curiosity and amazement of parents [43].

STEM programs also allow science to be brought closer to parents, especially those who have not accessed it previously, due to a lack of resources or bad experiences that threaten the ability to address scientific issues with their children [38]. In this sense, STEM activities make parents more confident and increase their interest in learning scientific topics and performing scientific tasks with their children [38].

Besides, a curriculum that includes STEM can also effectively involve parents in the STEM education of their preschool children [33]. In addition to the activities designed and offered by schools or other agencies, parents also perform STEM-related activities in their everyday environment, such as exploring nature, building, observing, playing with puzzles or games related to science, visiting places related to science [41]. The findings noted above reinforce the positive potential of STEM activities to promote parental involvement in those disciplines, inside or outside the educational settings.

4.7. Key Points of Vigilance Studying Parental Involvement

Some of the issues revealed in the empirical studies covered by this review are: firstly, most of the studies have small sample sizes, which might constrain the type of analysis and the generalizability of the results. Secondly, the participants' proximity and prior knowledge of STEM needs to be taken into consideration as a variable potentially affecting the programs and the study of parental involvement Thirdly, there are a few programs focused on STEM as integrated education initiatives; and, finally, there is a scarcity of emerging results that have been followed up in studying parental involvement.

5. Discussion

This article aimed to answer the question: What does the literature indicate about parental involvement in early childhood STEM education? to identify advances and gaps in this newly explored field [28,30,31]. The relevance of this review stand from the high potential of STEM education in the early years to generate positive social, technological, economic, and environmental changes [1,3,7]. Moreover, STEM in preschoolers has become an area of high interest in countries looking to reinforce their human and economic development. Nonetheless, the reported research has so far centered mainly on institutional programs inside or outside the school (i.e., Cabello et al., 2021 [6]), and little knowledge is available about the advances and new research lines regarding STEM in children at home or the parents' involvement in its development.

The results showed the relevance of parental involvement in STEM education during early childhood. Different forms of parental participation and their positive and negative effects on the configuration of interests, skills, and self-efficacy in STEM in children were detected. These include praise, feedback, and attention-getting strategies that promote children's STEM learning. In contrast, expressions of frustration, impatience or lack of interest, or a very directive style on the part of parents would hinder children's approach to STEM. Likewise, the association between the experiences, training, perceptions, and emotions of parents and the willingness and confidence of children to participate in STEM activities were identified. These findings are consistent with what has been stated in the literature about the relationship between parental involvement and the development of psychological characteristics and processes that would be at the basis of academic performance [4,5], such as children's motivation, interests, and self-efficacy. The need for parents to have support and information to facilitate their children's STEM learning was also detected.

Finally, the potential of activities to promote STEM learning in children and parental involvement beyond school was also identified. These activities, which can reach families from diverse social, economic, educational, and racial backgrounds, bring STEM content closer to children's context and daily lives. The above would give social and cultural relevance to STEM concepts, helping children connect new information to their meaningful reality and understand its impact on the environment [2,44]. This could be a springboard for them to develop STEM skills that, in the future, would enable them to engage in these disciplines and contribute to the achievement of the Sustainable Development Goals, reaffirming the positive effects of investing in the early years [7,45].

This systematic literature review will help researchers interested in STEM in preschoolers, incorporating parental involvement as a moderating variable. This can be a new research question. It will also be helpful for organizations that design or implement STEM activities aimed at families. Limited to a few papers but ample in scope, the findings of this study will provide relevant information to plan activities, establish objectives, contents, and methodologies, provide theoretical support, and anticipate the needs of children and parents, among others.

While the results are promising and attractive, it is essential to remember that they are based on a small number of investigations, mainly of a descriptive nature, carried out with small samples and a low geographical variability. These factors are a limitation of this review, as they reduce the possibility of extending the results to a broader population, so they should be analyzed and used with prudence. We recommend that future literature reviews broaden the search criteria to access a more significant number of empirical studies and generate more robust results. Moreover, the present literature review might be complemented with other meta-analysis or research reviews oriented to parental involvement in the disciplines—for instance, centered separately on early science, technology, engineering, and mathematics. This would provide a more comprehensive view, which could be compared to the present review focused on the STEM or STEAM, knowing that the activities occur on a continuum ranging from a lower to a greater degree of integration of the disciplines [2].

Nonetheless, it is worth having a panoramic overview of parental involvement in early childhood STEAM education, especially considering the relevance of the supportive role of parents in child development in the current pandemic context, in which homeschooling has brought a different perspective on parents' involvement in children's education. On the other hand, the use of different databases, beyond Web of Science and Scopus, is recommended. This will allow the access to studies published in emerging media and diversify the bibliographic sources, which will promote the multicultural perspective necessary to understand the dynamics of parental involvement.

Apart from the limitations described above, we have recommendations derived from the issues detected in the articles cited. For instance, increasing the sample size is possible if the study aims to generalize the conclusions. However, since parental involvement in STEM in preschoolers is still an emergent field of research, we think it is also valuable to opt for descriptive studies with small samples. Moreover, if working with samples that participate in workshops or programs, it is recommended to include a control group.

Likewise, we suggest investigating formal (e.g., classrooms) and informal contexts (e.g., home, museums, zoos). Future research might include those as search terms to make them visible in the analysis, because differences might appear between those types of education. Finally, it is worth pointing out the serendipitous results or emergent topics, even if they contradict previous findings. Researchers can detect new issues and research questions and critique their findings (e.g., parenting style and STEM education) in a collective, constructive way.

Beyond the limitations indicated, the results of this literature review also invite us to continue studying STEM education in preschools and parents' role in it. New research could draw on the exposed results to deepen and validate them, using more sophisticated designs and larger samples with fewer biases. Likewise, the encouraging findings could motivate future interventions with a multidisciplinary, integrated, and gender approach, incorporating art and including the involvement of diverse families. This is relevant because programs in early childhood are proven to be cost-effective [7], and family participation has been positioned as a crucial factor contributing not only to the academic achievement of children but also to the achievement of sustainable development goals [1,3].

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