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Teaching and Learning of Science during the Early Years

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EDITORIAL

Teaching and learning science during the early years

Kathy Cabe Trundle[1], **Mesut Saçkes** [2]

Abstract: Over the past two decades, science has increasingly become an integral part of early childhood curricula, and research on teaching and learning science in early years has emerged as an established field of study. Collectively, the findings of a growing body of literature suggest that introducing science in developmentally appropriate ways may support young children's learning of science concepts and scientific thinking skills. The increasing number of edited volumes and special issues, including this one, devoted to the topic of early childhood science teaching and learning indicates that early science education, as a field of study, will continue to attract researchers from early childhood and science education as well as educational and cognitive psychology.

Keywords
Early science education;
Preschool science education;
Teaching and learning of science

Research on the teaching and learning of science during children's early years of development has emerged as an established field of study over the past two decades. Collectively, the findings of a growing body of literature suggest that introducing science in developmentally appropriate ways may support young children's sensory explorations of their world and provide foundational knowledge and skills for lifelong science learning as well as a deeper appreciation of nature (Trundle, 2015; Trundle & Saçkes, 2012).

Despite the increasing number of research studies on early childhood science education, our knowledge about the teaching and learning of science during the early years remains limited compared to other domains such as literacy and mathematics (Trundle & Saçkes, 2012, 2015). Empirical studies, reviews, and policy analyses are needed to inform the theory and practice of teaching and learning of science in preschool and kindergarten classrooms.

The following research themes provide a foundation for further studies in the field (Siry, Trundle & Saçkes, in press): 1) development of children's scientific thinking and inquiry skills and how to support children as they engage with science; 2) play as a pedagogical tool for science learning and skill development; 3) children's emotions and motivation toward science; 4) the effectiveness of available science curricula and the design of developmentally appropriate science curricula for young learners; 5) accessibility of early science education for all children; 6) the integral link between science and language and young children's talk about and interaction with science concepts and phenomena; 7) the integration of science learning with other content domains; 8) outdoor and environmental education to support science learning; 9) family participation in young children's science learning; 10) educational materials and technology to support young children's science learning; and 11) parent and caregiver support of infants and toddlers as they begin to experience science concepts and skills.

The content of this special issue of the Journal of Childhood, Education & Society contributes to our understanding of several aspects of early science education including:

- how play-based inquiry activities support children's conceptual understanding of thermal-

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insulation and engagement with scientific and engineering practices (Fragkiadaki et al., 2021; Miller & Saenz, 2021)

- the role of language, question-explanation exchanges, and Dual Language Learning environment in learning science concepts (Åkerblom & Thorshag, 2021; Haber et al., 2021; Rumper et al., 2021)
- how early childhood teachers' perceptions of gender influence their science teaching practices (Hamel, 2021).
- how off-school visits promote young children's engagement with scientific inquiry and learning of science concepts (Roberts, 2021).
- The extent to which science concepts and skills are included in U.S. preschool curricula (Ocasio et al., 2021).

Teaching and learning science as inquiry during the early years should invite children to be cognitively, motivationally, and physically active participants in investigations where they ask questions, make observations and answer questions within the context of developmentally appropriate concepts and materials (Trundle & Saçkes, 2012). The findings of research studies over the last two decades, along with the studies included in this special issue, suggest that young children have potential to benefit from science learning opportunities (Carey, 2004; Güçhan-Özgül, 2021; Kuhn & Pearsall, 2000; Metz, 1997; Hobson, Trundle & Saçkes, 2010; Samarapungavan, Mantzicopoulos, &Patrick, 2008; Saçkes et al., 2020; Trundle & Saçkes, 2015).

Over the past two decades, science has increasingly become an integral part of early childhood curricula, and research on teaching and learning science in early years has emerged as an established field of study. The increasing number of edited volumes and special issues, including this one, devoted to the topic of early science teaching and learning indicates that early science education, as a field of study, will continue to attract researchers from early childhood and science education as well as educational and cognitive psychology.

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Research Article

Dramatic play as a means to explore and support preschool children's thinking about thermal insulation

Glykeria Fragkiadaki[1], Anna Armeni[2], Stella Zioga[3], Konstantinos Ravanis[4]

Abstract: Research in young children's ideas, representations, and pre-conceptions about the natural and technical world has a long history. Most of the studies in the field have used individual, semi-structured interviews as a methodological technique to generate and collect empirical data. However, less is known about how tracing procedures can come in line and be incorporated into everyday educational reality in early childhood settings in a way that reflects young children's interests and needs. The present study uses dramatic play to trace young children's thinking in science and advance their science learning experiences. The study focuses on a science concept young child are familiar with in everyday life though has not been thoroughly studied in the literature yet: thermal insulation. Empirical data from 6 pre-schoolers in Greece are presented. Qualitative data were collected through recordings of children's dialogues, children's drawings, field notes from the early childhood teachers, and photographs. The findings revealed that during their dramatic play children a) developed basic argumentation to express their thinking about the phenomenon; b) related the phenomenon with the thermal condition and changes in temperature; c) identified materials and objects with insulating properties and distinguish them from others with non-insulating properties, and d) came to the conclusion that the use of amplified insulation materials can lead to better insulation results. The outcomes of the study add to the research methodology in early childhood science education and inform practice providing a pedagogical framework that balances between play-based pedagogies and advanced learning outcomes in science for young learners.

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Keywords
Dramatic play; Ideas; Representations; Pre-conceptions; Science concept formation; Thermal insulation- melting; Solidification; Early childhood

Introduction

Research in young children's ideas, representations, and pre-conceptions about the natural and technical world has a long history (Ravanis, 2017). Several empirical studies have explored children's scientific thinking about a wide range of science concepts such as optical and sound phenomena (Delserieys et al., 2017; Pantidos et al., 2017; Ravanis et al., 2021; Smith & Trundle, 2014), the properties of matter phenomena, (Christidou et al., 2009; Kalogiannakis et al., 2018), mechanic and engineering phenomena (Hadzigeorgiou, 2002; Larsson, 2013), phenomena associated with electricity (Calo Mosquera et al., 2021; Kada & Ravanis, 2016; Rodríguez-Moreno et al., 2020; Solomonidou & Kakana, 2000), and e) astronomical and meteorological phenomena (Fragkiadaki & Ravanis, 2015; Malleus et al., 2017; Saçkes et al., 2016; Trundle & Saçkes, 2010). Most of the studies in the field have used individual, semi-structured interviews as a methodological technique to generate and collect empirical data sets. However, less is known about how tracing and eliciting procedures can be tailored to young children's educational needs and be incorporated into everyday early childhood educational reality in a way that reflects young children's interests.

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The present empirical study aims to explore how dramatic play (Fleer, 2011, 2013) can be used as a means to trace as well as to support young children's thinking in science. The study focuses on a science concept that children are familiarized with from the very early beginning of their lives but few studies in the field have explored: the concept of thermal insulation. Empirical data from six preschoolers, aged between 5 to 6 years old, in a kindergarten classroom in Greece are presented. As part of the study design, children's dramatic play was inspired by the children's book entitled "A Little Bit of Winter" written by Paul Stewart. Four diverse activity settings were organized by the two early childhood teachers of the classroom in collaboration with the research team to stimulate children's dramatic play about the story concerning the natural phenomenon. Qualitative data were collected through recordings of children's dialogues during dramatic play, children's drawings, field notes from the early childhood teachers, and photographs of children's dramatic play. Indicative case examples are presented. Drawing upon the system of concepts of cultural-historical theory the concept of the interrelation between everyday concepts and scientific concepts was used as the main analytical tool. It is argued that dramatic play can give an insight into the way young children think about thermal insulation and at the same support the formation of the concept through play-based settings.

The paper begins with a literature review of the challenges young children face in approaching thermal phenomena. This is followed by an overview of how dramatic play is conceptualized in the present study as well as the critical role of dramatic play in early childhood science education. The findings documented the way preschoolers conceptualized and approached the natural phenomenon of thermal insulation during their dramatic play. It was shown that through the intuitive dealing with materials and objects children a) developed basic argumentation to express their thinking and developed an explanation about the natural phenomenon, b) identified materials and objects with insulating properties, c) distinguished these materials and objects from others with non-insulating properties, and d) came to the conclusion that the use of amplified insulation materials can lead to better insulation results. What was also shown is that dramatic play allowed children to realize, unpack, share and use their everyday understandings and real-life experiences to start forming the scientific concept of thermal insulation. The study suggests dramatic play as a social and cultural activity for tracing and, at the same time, supporting the development of young children's ideas and thinking in science. The paper concludes with an insight into how the findings advance the research methodology in early childhood science education research. The outcomes of the study also inform practice providing a pedagogical framework that balances between play-based pedagogies and advanced learning outcomes in science for young learners.

Thermal Phenomena in Early Childhood Science Education

A limited number of empirical studies have shown young children face difficulties in conceptualizing thermal phenomena (Cain & Lee, 2020; Cruz-Guzmán et al., 2017; Kampeza et al., 2016). Most of these studies have focused on aspects of young children's understandings of simple changes in the state of water.

To categorize the mental representations of children aged between 5 to 11 years old, Russel et al. (1989) introduced and implemented a set of tasks related to the concept of evaporation. The categorization of young children's representations provided a systematic tracing and recording with specific reference to the notions of conservation, change of location, and change of form of the water. In her research about the circle of water in nature, Bar (1989) studied changes in the state of water concerning the retention of the water. It was shown that till the age of 6 to7 years old, children do not yet conceptualize that water or vapor retains while till the age of 8 years old can conceptualize the retention of water but not the retention of the vapors. In line with this research perspective, Bar and Galili (1994) found similar outcomes for early childhood children. Tytler (2000) also studied the development of 6 to 7 years old children's thinking about evaporation and condensation focusing on tracing patterns at their replies. Patterns were based on the description of the phenomena and not on the explanation of them or the interrelation with specific aspects of experimental situations. Another study also explored the mental representations of children aged between 5 to 6 years old about melting and solidification of salt which is mostly found in the state of solid in everyday life (Ravanis, 2014). This research has shown that the most critical aspect of children's thinking was the familiar state of salt as solid.

Ravanis and Bagakis (1998) after tracing the obstacles in children's 5 to 6 years old thinking, used a specialized teaching strategy to lead their thinking towards the approach of the stages of evaporation. Cruz-Guzmán et al. (2017) research also focused on the same topic researching with children aged between 2 to 4 years old. This research followed a process of predictions and experimental confirmation about the changes in the state of matter of everyday materials. Finally, Kambouri-Danos et al. (2019) implemented a teaching intervention into phases. During these phases, children between 5 to 6 years old were asked to do predictions and interpretations for several changes in the state of water aiming at recognizing changes in temperature such as cooling and warming as a reason for the changes.

From this limited number of studies, it can be seen that early childhood children approach thermal phenomena in a non-stable and non-general way. Children interrelate the temperature of objects with the size of the objects as well as recognize the thermal properties of the materials the objects are made of. Regarding the changes in the state of matter young children can conceptualize vapor as the outcome of boiling water. However, children at that age do not realize that vapor becomes water again but usually believe that it disappears or enters solid materials. Moreover, the cases that the changes in the state of the matter are conceptualized efficiently by the children are related to these changes that happen as everyday phenomena and do not apply in other materials.

Despite the variety of research studies related to children's largely understanding of the thermal phenomena, less is known about how young children conceptualize thermal insulation. This is particularly surprising given that young children are experiencing thermal insulation daily as an everyday phenomenon in real life. For example, they put on their coat in order not to be cold when they play outdoors, or they use food containers made with thermal insulation materials to keep their lunch warm at school. What is known until now from the empirical literature is that young children tend to conceptualize insulation as a property of the materials (Paik et al., 2007). Touching upon thermal insulation at a theoretical level, Fleer (2008) gives an insightful example to explain how young children think about science concepts. She mentions that children wear sweaters when they are cold, and they know that this will keep them warm. This is an understanding based on children's daily experiences. However, this does not mean that children know the scientific explanation that lays behind it. As a result, children are more unlikely to understand the interrelations in diverse settings such as when they are trying to keep warm in the water by wearing a surfing costume. Further empirical research must be done and deeper knowledge has to be gained in order to understand how young children think about this phenomenon they experience everyday and what scientific explanations do they form to approach the phenomenon. The present study seeks to explore how young children conceptualize and develop their thinking about thermal insulation. How dramatic play can be used as a means to trace as well as to support young children's thinking towards science concepts such as thermal insulation is elaborated in the next subsection.

Dramatic Play as a Pedagogical Practice in Early Childhood Science Education

The diverse psychological aspects of drama have been explored widely in the literature (Courtney, 1989; Wolf & Kase-Polisini, 1985; Wright, 1999). These studies have highlighted the critical role of the concept of drama in the process of the development of the personality. Beyond the psychological aspect, drama has a critical role in play-based pedagogical frameworks. Research has shown that drama in early childhood settings is a dynamic pedagogical practice and a valued learning medium that promotes cultural, social, emotional, and intellectual learning and development (Brown, 2017; Courtney, 1989; Gao & Hall, 2019; Neelands, 2002; Vidal Carulla et al., 2021). Following a Vygotskian (Vygotsky, 1987) and post-Vygotskian (Elkonin, 1977, 1978; Leont'ev, 1978) perspective, dramatic play is conceptualized here as the leading activity for preschool and kindergarten age children and is distinguished by other activities by indicating that during dramatic play young children take on a role of another entity, for example, they pretend to be another person, an animal, or an object and use objects in a symbolic way, for example, they use a cardboard box as a spacecraft (Bodrova & Leong, 1998). As Mellou (1994) argues, the value of dramatic play for young children lies in five basic functions: "1) it provides personal expression and catharsis of inner desires; 2) it helps the child to distinguish between reality and fantasy; 3) it provides for children's social adaptation: 4) it is dynamic for learning; and 5) it improves intellectual development and specifically creativity, through interaction, transformation and imagination" (p. 105). Through their dramatic play, young children express themselves in intellectual, affective, and embodiment levels. They learn about their social and cultural reality as well as about the natural, technical, and technological world. They communicate with their peers and the early childhood teachers, they set and accept rules, undertake different roles, and develop their self-regulation. Being in a role through their body positioning, their gesture, their speech, their tone of voice as well as through the mediation of cultural artifacts and the material surroundings, children create new abstract as well as concrete learning spaces. Through dramatic play, children also form their perceptions and interpret everyday life as well as transform and expand their reality through their imagination and creativity.

Despite the wide range of studies related to drama and dramatic play in the early years (Brown, 2017; Dunn, 2003; Furman, 2000) as well as the interrelation between drama and secondary and primary science education (Dorion, 2009; McGregor, 2012; Metcalfe et al., 1984; Ødegaard, 2003; Pantidos et al., 2001; Varelas et al., 2010), less is known about the role of dramatic play in early childhood science education. Limited research has shown that diverse forms of drama can be a key asset in learning and development in science in the early years.

Fleer (2011, 2013) has highlighted this dialectic interrelation at a theoretical level and has also introduced a play-based model of practice that combines drama and dramatic play with science, technology, engineering, and mathematics (STEM) concept formation. In her model named Conceptual PlayWorlds model (Fleer, 2018) she suggests using drama and dramatic play to stimulate young children to enter an imaginary situation inspired by a children's book. Being within an imaginary situation along with the early childhood teachers, children are introduced into problematic situations that require the formation of a set of science and/or STEM concepts in order to be solved. Thus, young children begin forming the concepts within the imaginary situation while they are experiencing the drama and as part of their dramatic play (Fleer et al., 2020; Rai et al., 2021).

Fleer (2013) also suggests that using drama as a pedagogical practice can unpack the emotional nature of young children's scientific learning in pre-school and support children's s scientific learning in early years. She argues that through dramatic play inspired by fairy tales young children can develop their scientific consciousness and craft scientific narratives about the concepts and the phenomena of the natural world. What is critical in this direction is that early childhood teachers bring together science and fairy tales into a form of scientific drama that is meaningful for the child and allows the child to explore the surrounding world through play and imagination.

Remountaki et al. (2017) also used dramatic play to explore the ideas of children between 5 to 6 years old for the phenomenon of dissolution of solid substances into liquids. It was found that the use of a puppet, handled by the early childhood teacher, stimulated children to develop their dramatic play and at the same time orient the children towards the formation of the concept of dissolution. As part of their dramatic play, children wonder about the phenomenon, used their everyday knowledge and experience to form a scientific understanding of the phenomenon, and managed to systematically engage with early forms of science methodology such as the development of the trial skill.

Kambouri and Michaelides (2014) have also touched upon the interrelation between drama and early childhood science education. Focusing on the concept of water circulation in nature their research has shown evidence that drama can facilitate children's scientific understanding and also lead to the improvement in the children's use of vocabulary concerning the science concept that is explored. As Kambouri and Michaelides argued (2014) what is critical when using drama techniques for teaching science in early years is to emphasize the development of children's understanding of the science topic under investigation rather than on the correct and efficient implementation of the drama techniques.

What we have learned from the above studies is that dramatic play has a critical role in supporting young children's engagement, learning, and development in science. However, more has to be learned about how dramatic play can be used to get a better insight into children's thinking in science and to support the formation of science concepts as part of the child's everyday educational reality. Focusing on the underexplored science concept of thermal insulation, the study reported to this paper seeks to address this gap by answering the following research question: How dramatic play creates the conditions for tracing and supporting the process of thermal insulation concept formation in early childhood settings?

Method

Study Design

The study design was based on children's dramatic play during everyday educational reality in early childhood settings. Children's dramatic play was inspired by the children's book entitled "A Little Bit of Winter" written by Paul Stewart. The story of the book is about the friendship of a rabbit and a hedgehog. The hedgehog is facing a problematic situation: he has never seen snow since he goes into hibernation each winter. While the hedgehog is sleeping throughout the winter, the rabbit is trying to keep a snowball for him. He decides to cocoon the snowball in a bunch of leaves to prevent snow from melting. When the winter ends and the hedgehog goes out of hibernation, he finds the leftovers of the snowball.

Four diverse activity settings were organized based on the story as part of the research procedure. Each activity setting was held on different days, during the period of two weeks, following the educational routines of the class and lasted approximately twenty-five minutes. During the four activity settings, children were given the time and space to explore their ideas, express their narratives and argumentation and collaborate with their partner in the dramatic story to find a solution to the introduced problem. The activity settings were organized as follows:

First activity setting: Engagement with the story. The first activity setting aimed at stimulating children to wonder and unfold their thinking about insulation. Children were encouraged to craft a narrative around their conceptualization of the phenomenon making interrelations with everyday real-life experiences and understandings about the phenomenon. The early childhood teachers read the story with the children. As a team, the children and the early childhood teachers discussed commented and reflected on the story. In that phase, early childhood teachers supported children to focus their attention on the concept of thermal insulation, melting, and solidification. The concepts were discussed descriptively, without using specific terminology or any other scientific explanation. Storytelling and the following discussions took place in a space of the classroom that the early childhood teachers had transformed to look like the forest that the two of the story animals lived (e.g., a tree, leaves, pieces of ice).

Second activity setting: Experiencing the story through dramatic play. The second activity setting aimed at stimulating children to explore the materials used in the story, that is leaves and ice. Children were encouraged to experience the phenomenon and make predictions, test, describe, and explain the phenomenon as well as craft a narrative around their explorations. Children were engaged in couples in a dramatic play inspired by the story using a set of props such as a tail and a pair of ears pretending to be in the character of the rabbit and the hedgehog. The focus of the dramatic play was to explore ways of preventing a piece of ice from melting. Children were given ice-cubes representing snowballs in their dramatic play. The leading question and problem to be solved by the children were "How can we keep the snowball?". In that activity setting children used the same materials that the rabbit had used in the book, that is leaves. Early childhood teachers supported children's explorations by posing questions and stimulating the children to wonder about the concept of thermal insulation, melting, and solidification (e.g., "Why are you cocooning the ice, rabbi?", "What do you expect happening after cocooning the ice?", "What do you think is going to happen if you do not do cocoon the ice", "How do you know this?").

Third activity setting: Expanding the story through dramatic play. The third activity setting aimed at stimulating children to explore a set of diverse materials in order to make predictions, test, describe and explain the phenomenon as well as craft a narrative around their explorations. Children and the early childhood teachers continued the dramatic play inspired by the story. The problematic situation that was introduced in that phase was expressed as follows: "We have now run out of leaves! What should we do to keep the ice as it is?". Children have at their disposal a set of additional materials and objects such as aluminum foil, paper napkins, a plastic bag, a piece of cloth. Children were encouraged to select the material they consider more appropriate for preventing ice melting as well as to express their argumentation (Convertini, 2019) regarding their choice (e.g., "Which material do you think that is more appropriate for keeping the snowball as it is?", "How do you know that?", "What will happen when you cocoon the ice with this material?").

Forth activity setting: Using drawings to overview the overall experience. The fourth activity setting aimed at encouraging children to draw their overall experience and their understandings of the natural phenomenon. Children also explained, commended, and created a narrative around their drawings which they shared with the early childhood teachers and their peers.

The dramatic play was present throughout children's engagement with the science concept during the activity settings. Children had the possibility to lead the dramatic play based on their interests. Early childhood teachers' role was supportive to children's explorations of objects and materials during the dramatic play. Early childhood teachers consistently stimulated children to express verbally their thinking as well as document their thinking around the science concept through drawings.

Participants

Six preschool children participated in the study. The children were aged between 5 to 6 years old and were attending one kindergarten classroom in an urban area in Greece. The six children participated in the data generation process after expressing their will to join the dramatic play initiated by the early childhood teachers of the classroom. Parents' informed consent was given. The study was approved by the Ethics Committee of the Department of Educational Sciences and Early Childhood Education of the University of Patras. Children had no previous engagement in teaching and learning interventions regarding the concepts of thermal insulation, melting, and solidification. Two early childhood teachers of the classroom also took part in the study. Both teachers had less than two years of teaching experience and had not previously participated in professional development programs for teaching science in early childhood settings.

Data Collection and Analysis

Qualitative data were collected through a) recordings of children's and early childhood teachers' dialogues during dramatic play (approximately 1 hour and 40 minutes in total); b) their drawings after each activity setting (24 drawings in total); c) field notes from the early childhood teachers (4 pages in total); and d) photographs of children's dramatic play (20 photographs in total). Conversational analysis (Pea, 1993; Sacks, 1995) of the transcripted dialogues and narratives were carried out supported by the documentation from the drawings, the field notes, and the photographs. The analysis aimed at capturing critical moments when, using dramatic play, children managed to start developing early forms of the science concept. Themes such as interrelation with the thermal condition and changes in temperature, interrelation with everyday life as well as codes such as mentioning heating sources, mentioning family routines and interactions with adults emerged from the empirical data during the qualitative analysis.

Results

The overall findings of the study have shown that dramatic play allowed children to a) develop basic argumentation to express their thinking about the phenomenon realizing that several materials and objects can prevent ice melting; b) relate the phenomenon with the thermal condition and changes in temperature; c) identify materials and objects with insulating properties and distinguish these materials and objects from others with non-insulating properties, and d) come to the conclusion that the use of amplified insulation materials can lead to better insulation results. What was also shown is that dramatic play created the conditions for the children to interrelate their everyday knowledge and experience about thermal insulation as an everyday phenomenon with a scientific explanation that is compatible with the explanatory model that can be used in education about the phenomenon. The detailed findings and indicative examples of how children start forming the concept of insulation through dramatic play are presented below.

Developing Basic Argumentation About the Phenomenon as Part of The Dramatic Play

The findings revealed that children unfold and expressed their ideas about the phenomenon as being in the character of the rabbit or the hedgehog while handling and experimenting with the materials and objects during their dramatic play (Figure 1).

Figure 1. Cocooning the ice-cube with leaves

In particular, the findings pointed to the ability of the children to generate basic argumentation to express their thinking about thermal insulation and provide an explanation about the phenomenon. The qualitative data analysis has shown that all the children (6/6) were able to provide an argument about the need for insulating the ice-cube to prevent melting. The following excerpt (Excerpt 1) illustrates indicative examples of children's argumentation for insulating the ice-cubes.

Excerpt 1: Children's arguments around insulating ice to prevent melting

Early childhood teacher (E): Hedgehog, what would you do? Would you wrap the snowball?

Hedgehog 1 (H1): I would wrap it.

E: Aaa, why?

H1: In order not to, not to… lose…. lose the cold.

[…]

E: Yes. And if we don't have leaves, will we wrap it or leave it like that?

H1: We will leave it like that.

E: What will happen if we leave it like that?

H1: It will melt.

[…]

Rabbit 1 (R1): With plastic.

E: Ah, with the plastic. Have you seen at your home wrapping cold things in plastic?

R1: We've seen ice wrap.

E: Why do you think this is happening? Does mom do it at home?

R1: [affirmative nod]

E: Do you know why she does this?

R1: Why?

E: Do you know?

R1: In order not to melt the ice-cubes.

[…]

E: Do you agree with your friend who chose to wrap it in foil?

H1: Yes.

E: So, you would wrap it with the same material?

H1: Yes.

E: Why?

H1: To keep it a little cold.

E: Have you seen something like this somewhere and thought about it? How did you think of that?

H1: Yes, my mom, when we don't have a bag to put it in, she puts it in aluminum foil so that they don't leave it, and then she keeps it that way.

The above excerpt illustrates how being in the role of the hedgehog or the rabbit and trying to provide a solution to the problem that emerged from the story children begun crafting a narrative around the science concept. This science narrative included arguments that are suggestive of the realization of cause and effect relations between elements related to the phenomenon such as that wrapping results to keep the cold (insulation) and not wrapping results to lose the cold (melting). What is also important here is that children used their everyday experiences to craft the science narrative and support their arguments.

Drawings were also used as a supplementary means for the children to express as well as document their thinking about thermal insulation. In the indicative drawings presented below (Figures 2 and 3) children drew the element that they consider as critical for the thermal insulation of the snowball, which is the leaves. In particular, at one drawing (Figure 3) one child also decided to draw an acorn in the snowball expanding the narrative about how snow is going to keep the acorn also fresh.

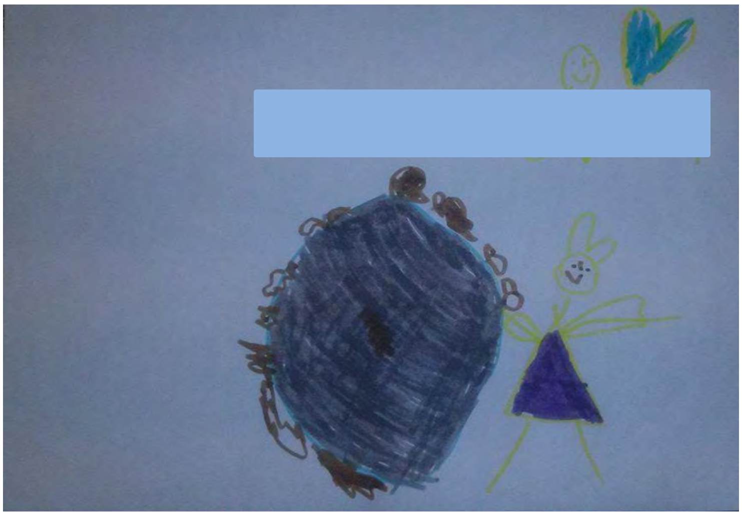
[redacted]

Figure 2. Drawing the rabbit cocooning the snowball with leaves

Figure 3. Drawing the rabbit cocooning an acorn with snow and leaves

Relating the Phenomenon with the Thermal Condition and Changes in Temperature

Four out of six (4/6) children were able to develop a basic explanation about the concept of thermal insulation relating the phenomenon with the thermal condition and changes in temperature (e.g., "It will not melt because it will be cold", "it will melt because spring will come", "it will melt because when spring comes everything melts because it is too hot", "it will melt because it is too hot"). This understanding is particularly important for approaching thermal insulation in a way that is compatible with the scientific model that can be used in early childhood education about this concept. Indicative examples of children's explanations related to the thermal condition and changes in temperature are presented in the following excerpt (Excerpt 2).

Excerpt 2: Science narratives around relating the phenomenon with the thermal condition and changes in temperature

> E: And if you don't wrap it with leaves, what will happen?
>
> Rabbit 3 (R3): It will melt!
>
> E: A! Why?
>
> R3: [laughs] Why? Because when spring comes, everything melts!
>
> E: A! Why is that?
>
> R3: Why? Because it's too hot!
>
> […]
>
> E: Would it melt? While if we wrap it with aluminium foil, what will happen?
>
> Hedgehog 2 (H2): It wouldn't melt.
>
> E: Why?
>
> H2: Why (…) because the sun can't burn the foil.

This excerpt illustrates how children expand their science narratives about insulation during their dramatic play. What is important here is that as the dramatic play evolves children reach and express more advanced understandings of insulation. It appears to be able to connect the phenomenon to thermal conditions and changes in temperature. This is a core idea in understanding thermal insulation.

Identifying Materials and Objects Based on The Criterion of Insulating Property and Distinguishing These Materials and Objects from Others with Non-Insulating Properties

During their dramatic play, children had the opportunity to choose from a wide range of materials and objects such as fabric, aluminium foil, plastic bag, a paper napkin to insulate the ice-cubes (see Figure

4).

Figure 4. Children select materials and objects to cocoon the ice-cube

The findings revealed that the children were able, to some extent, to approach the insulating or non-insulating property of the materials. This is evident from the fact that most of the children (4/6) selected aluminium foil as the most suitable for maintaining the "frozen snowball". Respectively, most of the children (5/6) considered the fabric inappropriate as a material for the preservation of the "frozen snowball". Each child developed their reasoning to justify his/her choice, whether it was about snowball management or the choice of material or object. Paper was not selected as an appropriate material from most of the children (5/6). Regarding the choice of paper as a suitable material, only one child chose it without giving a justification.

Excerpt 3. Using the criterion of insulating property and distinguishing materials and objects based on this criterion

E: Would you wrap it with something? Or would you leave as it is?

(R1): I would wrap it with…

E: Yes.

R1: (holds the aluminium foil)

E: With that?

R1: [affirmative nod]

E: Do you know what that is?

R1: Aluminium foil.

E: Ah! And why would you wrap it with this and not with the rest?

R1: In order not to melt…

[…]

E: If you wrap the snowball with this fabric, what will happen?

R1: I think it will melt.

[…]

E: Are you thinking of something else that we could wrap around so it wouldn't melt? Something you've ever seen at home.

R1: With plastic.

E: Ah with the plastic. Have you seen your home wrap cold things in plastic?

R1: We've seen ice wrap.

[…]

E: Would you choose the napkin?

Hedgehog 2 (H2): No.

E: Why?

H2: Because it would melt.

E: It would melt. While with what you chose, what will happen?

H2: It wouldn't melt.

[…]

E: So, what materials did you choose?

Rabbit 3 (R3): Aluminium foil and a bag.

E: And if you don't wrap the snowball with something, what will happen?

R3: It will melt. Look at the water (means the water from the ice melting)!

E: How do you know?

R3: Because look at the water! The school is full of!

E: But what if we wrapped the snowball with this fabric?

R3: It will melt again!

E: Why do you say it will melt again?

R3: Why? (shakes hands as a sign of wonder). See for yourself why. Look, what does it look like!

E: What does it look like?

R3: Water!

The above excerpt demonstrates that children were aware of the fact that different qualities and types of materials and objects can lead to diverse results regarding thermal insulation. The dialogues highlight that this realization allowed children to distinguish materials and objects as efficient and non-efficient options in insulating the ice-cubes during their dramatic play. What is also important here is that, while playing, children develop a trial skill to test the efficiency of the materials (e.g., E: How do you know? R3: Because look at the water! The school is full of!).

Realizing That the Use of Amplified Insulation Materials Can Lead to Better Insulation Results

While being in dramatic play as the characters of the story and handling the provided objects and materials, children also appeared to be able to realize that the use of more amplified insulation materials can lead to better insulation results. Regarding the choice of a plastic bag as a suitable material, one child chose it as the main material, emphasizing the quantity of the bags that should be used. That is, he considered plastic bags to be suitable for wrapping snowballs, provided they were “many”. For example, “I know why if we wrap one, one, one, one, once it gets there it won't melt”.

Excerpt 4. Realising that amplified insulation materials can lead to better insulation results

E: Or would you choose something else?

R3: More bags! Not just one!

E: Ah! Why?

R3: Why? In order not to melt!

E: Have you seen this somewhere? How do you know?

R3: I know this because if we wrap one, one, one, one, once it gets up there and it is no way it will melt!

E: With bags! So, in other words, you say that we have to wrap it, but with many, many, many bags.

R3: Yes.

E: Is one not enough?

R3: (…) No.

The excerpt presented here showcases that through their extensive engagement with the concept during dramatic play children were able to gradually deepen their understanding of diverse aspects of thermal insulation. The argumentation in the above excerpt is suggestive that the child realized that amplified insulation solutions can lead to better insulation results. What lies behind this realization is the advanced understanding that layers of insulation can block thermal transfer.

Conclusions and Discussion

The present study explored how dramatic play created the conditions for tracing and supporting the process of thermal insulation concept formation in early childhood settings. Evidence showed that through dramatic play inspired by a children's book, preschool children were able to conceptualize thermal insulation and develop explanations about the phenomenon. What was also found is that following the flow of children's dramatic play early childhood teachers managed to pose questions and better unpack children's thinking and stimulated them to wonder more thoroughly and develop their understandings about thermal insulation within play-based settings.

In particular, the qualitative analysis of the empirical data showed that dramatic play allowed children to a) develop basic argumentation to express their thinking about the phenomenon realizing that several materials and objects can prevent ice melting; b) relate the phenomenon with the thermal condition and changes in temperature; c) identify materials and objects with insulating properties and distinguish these materials and objects from others with non-insulating properties, and d) come to the conclusion that the use of amplified insulation materials can lead to better insulation results. The overall analysis also highlighted that dramatic play created the conditions for the children to make conceptual bridges between their everyday knowledge and experience about thermal insulation and a scientific understanding of the concept. Almost all children (5/6) reported experiences from their daily lives such as domestic routines, housekeeping, cartoons, free play with toys, objects and materials, during the interaction process with their friends and early childhood teachers. One child initially reported seeing his mom at home wrapping "ice" in plastic to keep it from melting. His peer, listening to his friend, agreed that his mom does the same and even added that when she does not have bags, she wraps them in aluminum foil. Another child reported something related to the general issue, stating that he knew that the snow would melt at some point because it had snowed in his apartment building. This is not directly related to the choice of material but suggests an appropriate correlation of the child with the subject. What was also important is that children used the book several times during their dramatic play to get more information from the illustrated pictures regarding the materials and the procedure of thermal insulating the snowball. This is suggestive that children were motivated through dramatic play to approach thermal insulation as a real-life phenomenon and as a real-life problem that has to be solved. The dramatic framework reinforced children's engagement with the collective science experience. At the same time, it allowed early childhood teachers to follow and process children's narratives and actions in a more naturalistic way than interviewing children.

The present study adds to the literature in a twofold way. Firstly, the findings provide important insights into a science concept that has not been previously explored systematically in the literature of early childhood science education research. This is particularly important given the fact that young children experience thermal insulation as an everyday phenomenon in their daily life. A better understanding of how young children think and wonder about thermal insulation can orient and shape teaching and learning interventions in early childhood settings. Interventions tailored made to young children's conceptual interests and needs can support children to form explanatory models about thermal insulation that are compatible with the models used in early childhood education.

Secondly, the study provides an alternative to the traditional tracing procedures of children's ideas, mental representations, and pre-conceptions. The study demonstrates empirical evidence of how dramatic play can be used for tracing as well as supporting young children's ideas and thinking in science. Thus, the evidence allows us to rethink tracing procedures in early childhood science education as social and cultural activities incorporated into the child's everyday educational reality. This realisation informs everyday practice providing a pedagogical framework that supports early childhood teachers to promote young children's engagement with the natural and technical world through play-based settings and in a way that is meaningful and enjoyable for the children.

The study concludes by highlighting the need for conducting further research on children's ideas about thermal insulation. Future research on this theme can consider the expansion of the number of participants as well as the design of a precursor model that illustrates the challenges as well as the opportunities and the possibilities young children have while approaching thermal insulation in early childhood settings. What is also important to be considered in future research is the need for designing and implementing playful and meaningful for the child procedures for tracing and detecting young children's ideas, representations, and pre-conceptions in science.

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Research Article

Portrait of early science education in majority dual language learner classrooms: Where do we start?

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Abstract: Despite the growing interest in early science education, there is much left to be explored, particularly in majority Dual Language Learning (DLL) classrooms. The current study examined 1) early science opportunities across classroom contexts in majority Spanish-English DLL Head Start classrooms, 2) the languages (i.e., English and Spanish) that teachers used to engage DLL children in science, 3) and how teachers' discussion of scientific and engineering practices and disciplinary core ideas related to children's academic outcomes. In a sample of 411 children (ages 3-5) from 34 Head Start classrooms, the current study found that teachers discussed and encouraged more practices during science lessons than circle time, dramatic play, and story time. There were no differences in teachers' discussion of core ideas across contexts. Teachers used the same amount of English and Spanish to discuss practices and core ideas. Teaching physical science was associated with children's science outcomes. Making observations and discussing life science were associated with children's math outcomes. Teaching math, making observations, and developing and using models were related to children's executive functioning. Findings from this study demonstrate that science opportunities occur across preschool classroom settings. Additionally, it provides evidence that teachers may be supporting DLL children's home language while discussing science. Finally, results indicate that teaching science supports children's academic performance in several outcomes. These findings have implications for DLL education policy as science may be a domain where teachers can support children's home language and their learning across multiple domains.

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Early science education; Dual language learners; Head Start; Preschool

Introduction

In recent years, within the United States, there has been a call for increased support of early science education (e.g., Office of the Press Secretary, 2016) and equitable learning environments for ethnically and linguistically diverse populations (National Association for the Education of Young Children [NAEYC], 2019). Yet, despite this call, relatively little is known about how teachers currently engage in science within preschool classrooms (Greenfield et al., 2009; Piasta et al., 2014; Saçkes et al., 2020*)*. Increased knowledge about how to support science learning is especially important for young Hispanic children as Hispanics are disproportionately underrepresented in Science, Technology, Engineering, Mathematics (STEM) careers (Kennedy et al., 2021; U.S. Bureau of Labor Statistics, 2020). Additionally, Hispanic children, particularly those from Spanish-speaking households, are disproportionately more likely to grow up in poverty, putting them at greater risk for early academic achievement gaps that begin early and widen over time (Duncan et al., 2007; Fitzpatrick et al., 2014; Hart & Risley, 2003; Morgan et al., 2016). These achievement gaps affect well-studied learning domains like language (Hart & Risley, 2003), but also critical areas like science (Morgan et al., 2016), math

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(Duncan et al., 2007), and executive function (EF) (Fitzpatrick et al., 2014).

Research demonstrates that high-quality preschool experiences have ameliorated academic achievement gaps for Hispanic Spanish-English Dual Language Learning (DLL) children (Buysse et al., 2014; Castro et al., 2017; Yazejian et al., 2015). More specifically, teacher engagement in early science inquiry is ripe with opportunities for these high-quality interactions (Kook & Greenfield, 2021; Whittaker et al., 2020) and has been shown to improve children's science and math skills (Piasta et al., 2015).

However, little is known about how teachers engage in early science in preschool and how teachers might specifically support DLL children in this domain (Rumper et al., 2021). In addition, few studies have investigated how preschool science affects children's outcomes in majority Hispanic, Spanish-English DLL classrooms (Banse, 2019). To address the need to support early science learning, the current study aims to paint a portrait of early science opportunities occurring in majority DLL classrooms. Furthermore, it will examine how preschool science relates to Spanish-English DLL children's academic outcomes.

Current State of Early Science Education in the United States

Recently, the Office of the Press Secretary (2016) expressed an urgent national need to advance science education for young learners. As a nation, the U.S. falls behind many developed and developing countries in science education. High school students in the U.S. ranked 38th in science achievement out of 71 listed countries (Desilver, 2017). Given the lagging science achievement of older students in the U.S. (Desilver, 2017), there is a need to understand current practice around early science education and to bolster support for young learners. As opposed to devising ways to helping older students "catch up" in the domain of science, the current study aims to examine how teachers engage in and support science in an early educational setting.

A Framework for Early Science Education

A new dynamic vision of scientific inquiry has arisen, one that diverges from the antiquated view of science education. The Framework for K-12 Science Education (National Research Council, 2012) offers a definition of science that no longer involves simply memorizing formulas or facts but allows for identifying opportunities for scientific inquiry in everyday contexts. It contains three complementary components: scientific and engineering practices, disciplinary core ideas, and crosscutting concepts (National Research Council, 2012). Scientific and engineering practices are the behaviors teachers and children engage in to support understanding (e.g., making predictions, making observations, documenting, analyzing and interpreting data, etc.). Disciplinary core ideas are the content that children learn (e.g., life science, earth and space science, physical science). Crosscutting concepts are the ubiquitous concepts children can understand from scientific inquiry to draw larger conclusions about the world (e.g., patterns, structure and function, cause and effect, etc.). Although this framework was designed for the K-12 educational system, it is flexibly adaptable for the early childhood setting and relevant for young learners (Greenfield et al., 2017; Saçkes et al., 2009; Trundle & Saçkes, 2012). For example, on the playground, children may notice that the leaves on the trees change colors or fall off as the weather gets colder, but the tree trunk remains the same. This one example presents an opportunity for children to engage in making observations (i.e., a practice) to support their understanding of life science content (i.e., core idea) and the concept of stability and change (i.e., crosscutting concept). The current study incorporates the early childhood version of the Framework for K-12 Science Education which seamlessly connects to later science learning goals (National Research Council, 2012).

Science Across Classroom Contexts

Few studies have investigated naturally occurring early science learning opportunities in preschool classrooms (Piasta et al., 2014; Rumper et al., 2021; Tu, 2006). Although science can be promoted throughout various contexts, it is often misperceived as an isolated content domain. Due to this misconception, a great deal of research on science education in early childhood classrooms has focused on science as an isolated learning experience (Brenneman et al., 2009; Gerde et al., 2013). Given the boundless definition described by the Framework for K-12 Science Education, science learning can occur across multiple early childhood classroom contexts. This perspective has been adopted in several studies (Neuman, 1972; Piasta et al., 2014; Tu, 2006). Neuman (1972) viewed these opportunities as "formal", "informal", and "incidental sciencing". Piasta and colleagues (2014) investigated the science and math opportunities occurring in Head Start classrooms throughout the day and found variation across classrooms regarding the amount of time spent on science and math. However, no study to date has explored science learning opportunities that are embedded across preschool classroom contexts (i.e., circle time, story time, and dramatic play).

While these informal opportunities for science learning are present across multiple contexts, little research has explored how teachers support children's engagement in science practices and understanding of core ideas throughout a typical classroom day. Circle time is a context teachers could use to introduce science content prior to a hands-on investigation and provide opportunities for children to engage in science practices. For example, a teacher may pass around seeds at circle time for children to use their senses to make observations and make a plan for an investigation to understand what seeds need to receive in order to grow. Story time is another classroom context that can support children's science learning as teachers can encourage children to observe and describe attributes of objects within a book (e.g., the shape of various fruits), make predictions about what may happen next (e.g., the sun will dry the puddles from the rain), and note crosscutting concepts (e.g., the wind caused the girl's hat to blow off) (Kook & Greenfield, 2021). Dramatic play is another context that lends itself well to supporting children's science learning. For example, a teacher may help children think about the crosscutting concept of scale, proportion, and quantity and help them engage in the science practice of using math as they set the table with plates and pretend food. The current study aims to expand upon this by examining teacher use of science practices and core ideas from the Early Science Framework (Greenfield et al., 2017; National Research Council, 2012) that occur during a science lesson, circle time, story time, and dramatic play.

Science as Hands-on and Minds-on Learning for DLL Children

Several recent studies have highlighted the importance of leveraging science as an engaging domain to create high-quality early learning experiences for DLL children (Brenneman et al., 2019; Lange et al., 2021) as early science learning experiences are associated with later science achievement (French, 2004; Peterson & French, 2008). Typically, developmentally appropriate pedagogy in preschool is based on hands-on and cognitively engaging (i.e., minds-on) experiences that are responsive to children's identities and cultures (NAEYC, 2020). Science includes hands-on contextual learning (Trundle & Smith, 2017), where teachers can use different modalities to explore relevant science content and to determine DLL children's understanding of the material (e.g., through drawings, actions, etc.) (Lee et al., 2006). Thus, even if DLL children do not yet know the words to express their understanding of phenomena (e.g., changing the angle of a ramp changes the distance a ball rolls) they are able to demonstrate their knowledge. Additionally, having hands-on experiences is particularly important for DLL children as it can decrease cognitive load and facilitate language learning (Lee et al., 2006). Early science opportunities also include a minds-on component, where children are challenged to think critically to identify and solve problems. Given that science is a rich learning domain with the potential to increase hands-on and minds-on inquiry for young DLLs, there is a need to support teachers in integrating it into their classrooms. Currently, however, there is a lack of research examining how science is implemented in preschool classrooms with Spanish-English DLL children.

Language Support around Science

In addition to a need to support early scientific inquiry, DLL children also require home language support in the classroom. Prior literature demonstrates that when teachers use Spanish in the classroom, Spanish-English DLL children have higher language, math, social-emotional skills, and better approaches to learning (Burchinal et al., 2012; Chang et al., 2007; Limlingan et al., 2020, Limlingan et al., 2021; Raikes et al., 2019). However, many studies have found that Spanish is often used infrequently, if at all, within preschool classrooms (Franco et al., 2019; Sawyer et al., 2018). Thus, begging the question, "How are teachers using English and Spanish to discuss and engage in science?". This could be a fundamental question as DLL children enter preschool programs with varying levels of English (Baker & Wright, 2017) and may not comprehend the specific science content vocabulary due to language barriers. One prior study (Rumper et al., 2021) found that teachers used a mix of English and Spanish during science lessons to support DLL children; however, it is unknown whether this language support around science extends to other typical contexts in early childhood classrooms. Thus, more research is needed to understand how teachers use English and Spanish to discuss and support science across classroom contexts.

Science as a Learning Domain for Supporting Children's Academic Outcomes

At a child level, studies have demonstrated associations between children's science scores and their language (Guo et al., 2016; Westerberg et al., 2021), EF (Frechette et al., 2021; Gropen et al., 2011; Nayfeld et al., 2013), approaches to learning (Bustamante et al., 2017), and math skills (Kermani & Aldemir, 2015). Previous intervention studies indicate that when preschool teachers engage in science, there are gains in children's outcomes across multiple learning domains (Guo et al., 2016; Saçkes et al., 2020; Vitiello et al., 2019; Whittaker et al., 2020). Studies have specifically shown that children make gains in their vocabulary when teachers are involved in science interventions (Guo et al., 2016). More research, however, needs to be conducted to determine how specific teacher-level factors are related to children's academic outcomes in other domains like math, science, and EF. The few studies that have examined associations between teachers' use of science in the preschool classroom and child outcomes have exhibited mixed findings. One study conducted by Whittaker and colleagues (2020) investigated the effects of a science intervention, MyTeachingPartner- Math/Science, on children's math and science outcomes and found differences between treatment and control groups. Children whose teachers were involved in an intervention had higher math and science outcomes than children whose teachers were not. Another study discovered trend-level associations (i.e., $p < .10$) between teachers' use of scientific and engineering practices and children's science outcomes (Vitiello et al., 2019). In naturalistic observations, Piasta and colleagues (2015) found that children in classrooms with more opportunities for science and math learning had higher math and science outcomes. However, in other studies examining early classroom science experiences, opportunities for science learning were not associated with children's concurrent or long-term science outcomes (Saçkes et al., 2011; Saçkes et al.,2013). Given mixed findings from prior studies, it is important to further examine how science teaching relates to children's academic outcomes.

Current Study

The current study aims to fill several gaps in the literature by examining the state of science learning opportunities in preschool classrooms. Additionally, little is known about teachers' use of English and Spanish support for DLL children around science. Finally, this study aims to fill the research gap surrounding the relation between teachers' engagement in science as defined by the K-12 Framework for Science Education (National Research Council, 2012) and children's academic outcomes.

Research Questions and Hypotheses

To address the gaps in the literature, the present study

1) describes science lessons conducted in majority DLL Head Start classrooms and opportunities for early science learning throughout the day,

2) examines how preschool teachers use English and Spanish language when discussing science practices and core ideas and,

3) and examines relations between teachers' science use throughout the day and children's academic outcomes (i.e., science, math, executive functioning, and vocabulary).

The first aim is exploratory in nature and descriptive. Given the community in which this study took place, it was hypothesized that teachers would use a mix of English and Spanish in discussing practices and core ideas (Rumper et al., 2021). It was hypothesized that children whose teachers discussed more practices and core ideas would have higher academic outcomes.

Method

Participants

Lead and assistant teachers (*N* = 66) were recruited from 34 majority Spanish-English DLL classrooms across six Head Start centers during the 2017-2018 school year. Most teachers in the study reported being Hispanic (92.40%). See Table 1 for demographics. All teachers were female and had an average of 12.52 years of experience teaching preschool (*SD* = 6.25). The majority of teachers reported having a bachelor's degree (56.10%). Teachers also had varying levels of experience with science professional development. The majority reported having received a moderate (53.00%) or minimal (22.70%) amount of professional development workshops focused on early science education.

Table 1. Teacher level demographics

		%	*M*	*SD*
Ethnicity				
	Hispanic	92.40%		
Race				
	White Non-Hispanic	6.10%		
	Black Non-Hispanic	1.50%		
Years Teaching			12.52	6.25
Highest Level of Education				
	High School Diploma or GED	7.60%		
	Some college no degree	12.10%		
	Associate degree	15.20%		
	Bachelor's degree	56.10%		
	Some Graduate Courses no degree	1.50%		
	Master's, Doctoral, Medical, Law or other professional degree	7.60%		
Science Professional Development				
	None	6.10%		
	Minimal amount	22.70%		
	Moderate amount	53.00%		
	Great deal	18.20%		
Primary Language				
	Spanish	81.80%		
English Ability			2.67	.92
	Not at all	9.10%		
	Not well	36.40%		
	Well	33.30%		
	Very well	21.20%		
Spanish Ability			3.32	1.00
	Not at all	7.60%		
	Not well	15.20%		
	Well	15.20%		
	Very well	62.10%		

Note. N = 66.

Many teachers reported speaking some level of English, ranging from "not at all" (9.10%) to "very well" (21.20%). Most teachers in the study reported being able to speak some level of Spanish. Reports ranged from "not at all" (7.60%) to "very well" (62.10%). On average, teachers reported having higher levels of Spanish proficiency (*M* = 3.32, SD = 1.00) than English proficiency (*M* = 2.67, *SD* = .92).

A total of 411 Spanish-English DLL Head Start children were also recruited for participation as part of a larger study. Children ranged in age from 37 to 63 months (*M* = 49.28, *SD* = 6.69) and 48.40% were female. Classrooms contained an average of 18.83 (*SD* = 1.94) Spanish-English DLL children out of an average total of 19.73 (*SD* = 1.38) children per classroom. While Head Start Performance Standards state that teachers should support DLL children's English and home language development (Head Start Program Performance Standards, 2018), there is little guidance about how much each language should be used.

Procedure

Using a mixed methods approach, the current study sought to describe science occurring in majority Spanish-English DLL preschool classrooms and to examine relations between science instances and children's academic outcomes. This study was observational in nature.

The current study was approved by the Institutional Review Board of the University of Miami, protocol #20171061. All data collection took place during the 2017-2018 school year. Head Start center directors were approached as part of a larger study, Enfoque en Ciencia (Institute of Education Sciences Grant# R305A130612), and if they opted to participate, teachers and parents were invited to join. Participation in the study was voluntary. During the consenting process, teachers were told that the researchers were interested in learning about children's development and factors that might affect it. Participating teachers were asked to carry out four classroom routines (i.e., science lesson, circle time, story time, and dramatic play) as they normally would. They were also informed that these settings would be video recorded by trained research staff. Consenting teachers received gift cards for their participation in this study. Parents were consented for their child's participation in the study. They were told that researchers were interested in learning about children's development and school readiness and that their child would be videotaped and assessed if they chose to take part in the study.

In the fall of 2017, all children were assessed using a language screener to determine their dominant, or stronger language and EF. In the spring of 2018, children were assessed in their dominant language on science, math, and vocabulary measures. Teachers' classrooms were video-recorded on one or two mornings during the spring. Classrooms were video-recorded for 15-20 minutes in the following contexts: a science lesson, circle time, story time, and dramatic play for an average total of 58.18 minutes (*SD* = 12.45). The topic of the science lesson and the delivery format (e.g., whole group, small group, outside, etc.) were the teacher's choice.

English-Spanish bilingual undergraduate research assistants were trained to transcribe videos using Systematic Analysis of Language Transcripts (SALT) (Miller et al., 2011) conventions. Transcripts were coded for scientific and engineering practices and disciplinary core ideas using a rubric aligning with the K-12 Conceptual Framework for Science Education (National Research Council, 2012) and the Early Science Framework (Greenfield et al., 2017). See Table 2 for a description of specific science practices and core ideas coded and Appendix A for the codebook. Teachers' English and Spanish language use were coded at a word level.

Measures

Scientific and Engineering Practices and Disciplinary Core Ideas

All videos collected were transcribed according to SALT conventions (Miller et al., 2011). Thus, utterances were segmented into C-units, or independent clauses and all of their modifiers. The Early Science Framework (Greenfield et al., 2017), derived from the K-12 Framework for Science Education (National Research Council, 2012), was used to create a codebook including scientific and engineering practices and core ideas. Scientific and engineering practices and core ideas and were coded by a graduate student and undergraduate researchers in both English and Spanish at the C-unit level. For example, if a teacher used a practice or core idea in a C-unit, it was coded as that practice or core idea. Core ideas were defined as facts around science that teachers stated or requested from children.

Table 2. Scientific and engineering practices and disciplinary core ideas coded

	Science Component	Description
Scientific and engineering practices: the *behaviors* that scientists engage in to explore and develop knowledge.	Making Observations	How teachers encourage or help children use their senses and tools for observation to collect information about their world (e.g., using their hands to feel if a rock is smooth or rough; examining a caterpillar with a magnifying glass).
	Asking questions and defining problems	How teachers encourage or help children to ask larger questions about what they know and what they do not (e.g., "What's inside of a ball?") or to identify something that needs a solution (e.g., "The juice spilled on the floor and we need to clean it up").
	Making predictions	How teachers encourage or help children use knowledge from observations and prior experiences to make an informed hypothesis (e.g., "This rock is heavy. I think it will sink in the water").
	Developing and using models	How teachers encourage or help children to mentally and physically represent real-world phenomena to develop and deepen their understanding (e.g., drawing a house and building it in the block center).
	Planning and carrying out investigations	How teachers encourage or help children organize and implement a procedure to test a hypothesis (e.g., rolling marbles down ramps of varying inclines to see which one goes faster).
	Using math and computational thinking	How teachers encourage or help children to use mathematics to quantify and describe their world (e.g., measuring the height of two plants and deciding which one is taller).
	Documenting	How teachers encourage or help children record and organize data (e.g., drawing pictures to show which objects "sink" or "float" during an experiment).
	Analyzing and interpreting data	How teachers encourage or help children make sense of data (e.g., determining which objects "sink" or "float" after an experiment).
	Constructing explanations and designing solutions	How teachers encourage or help children interpret data to generate evidence-based answers to their questions and design solutions to problems (e.g., "I know spiders are alive because they crawl").
Disciplinary Core ideas: the *content* that provides a context for engaging in practices and developing an understanding of crosscutting concepts.	Physical Science	When teachers discuss, encourage children to discuss, or help children to learn about: • Matter and its interactions • Motion and stability • Energy, light and sound waves, and their applications
	Life Science	When teachers discuss, encourage children to discuss, or help children to learn about: • Molecules and organisms • Ecosystems • Heredity and traits • Biological Evolution
	Earth and Space Science	When teachers discuss, encourage children to discuss, or help children to learn about: • Earth's place in the universe • Earth's systems • Earth and human activity
	Engineering and Technology	When teachers discuss, encourage children to discuss, or help children to learn about: • Engineering Design • Links among engineering, technology, science, and society
	Math	When teachers discuss, encourage children to discuss, or help children to learn about: • Shapes, sizes, sorting, patterning, and counting *Note: This differs from the practice "using math and computational thinking" in that the content focuses on math as a learning goal and not an action.*

Note. Adapted from the Early Science Framework (Greenfield et al., 2017) and the Framework for K-12 Science Education (National Research Council, 2012).

Undergraduate research assistants were trained to use the codebook derived from the Early Science Framework. Transcripts were randomly assigned to researchers and coded using Atlas.ti version 8.0. All research assistants were required to pass reliability with a Krippendorf's alpha of .67 or higher (Hayes & Krippendorff, 2007). On average, reliability for practices was α = .82, and for core ideas, α = .79.

Teacher use of Spanish and English in Practices and Core Ideas

Teachers' use of Spanish and English during practices and core ideas were also coded in Atlas.ti version 8.0. Research assistants coded English and Spanish at the individual word level or as tokens to account for code-switching. For example, on some occasions, teachers would say "baking soda" in English and the rest of the utterance in Spanish. Proper nouns, filled pause words, and singing were not coded as English or Spanish. If coders were unable to determine if a word was English or Spanish (e.g., solar, rural, etc.), they went back to the recording. Using the codes from practices and core ideas and English and Spanish language codes, percent scores were computed. For example, to determine the percent of English used during practices, the number of English words used during practices was divided by the total number of English and Spanish words used during practices and multiplied by 100. This process was used to calculate four scores for each teacher: percent of English used during practices, percent of Spanish used during practices, percent of English used during core ideas, and percent of Spanish used during core ideas.

Dominant Language

Children were assessed using a language screener in English and Spanish to determine their dominant, or stronger language using two subtests of the prelas2000 (Duncan & De Avila, 1998). The Art Show subtest was used to gauge children's expressive language and has a reliability of α = .90. The Simon Says subtest was used to screen children's receptive language skills and has a Cronbach's alpha of .88. The use of these two subtests to screen Head Start DLL children has been deemed valid and reliable (Rainelli et al., 2017). Children's English Art Show and Simon Says were added to create an "English" score and their scores on the Spanish versions of these subtests were added to create a "Spanish" score. The "English" and "Spanish" scores were compared. If English was higher, children were deemed "English dominant" and received subsequent assessments in English. Comparably, if the Spanish score was higher, children were deemed "Spanish dominant" and received the remaining assessments in Spanish.

Science

To measure science achievement, children were assessed in their dominant language on Lens on Science or Enfoque en Ciencia (Greenfield, 2015). Lens and Enfoque are equated English and Spanish versions of a computer adaptive IRT-based science assessment. These measures were created to assess a range of preschool children's science knowledge as it relates to the Framework for K-12 Science Education (National Research Council, 2012). It covers the following areas: scientific and engineering practices, crosscutting concepts, and core ideas. Lens and Enfoque have a reliability of .86 when the standard error is fixed at .34 as it was for this study. The assessment has a pool of 498 items calibrated using the dichotomous Rasch model. Generally, children receive a subset of around 35 items that are tailored to their ability level. Lens and Enfoque are administered on a touchscreen computer and children wear headphones to hear prompts instructing them to respond.

Math

The Research-based Early Mathematics Assessment-Brief (REMA-Brief) (Clements et al., 2008) was used to measure children's math abilities. The REMA-Brief is a valid and reliable tool for detecting differences in children's math achievement and is appropriate for use with preschool children. The assessment is composed of 20 items and is directly administered to children by an assessor. It is designed to cover a range of early math skills, including numerals, subitizing, counting, comparing numbers, composing numbers, shape, composing shapes, and patterning. It has an overall reliability of .94 and demonstrates concurrent validity with the PPVT (.74). All assessors were trained rigorously to administer the REMA-Brief to preschool children and to code their answers for correctness.

Executive Function (EF)

Children's EF skills were measured using the Pencil Tap task from the Preschool Self-Regulation Assessment (PSRA) (Rueda et al., 2005; Smith-Donald et al., 2007). Pencil Tap task is a direct assessment that measures children's inhibition, working memory, and cognitive flexibility. During this assessment, children are instructed to tap their pencil once if the assessor taps their pencil twice and vice versa. Each child is administered 16 trials and a score is obtained by taking the percent of the total number of correct trials. The Pencil Tap task demonstrates measurement equivalence across race (i.e., African American children), ethnicity (i.e., Hispanic children), and sex (Denham et al., 2012). It has good concurrent and construct validity (Smith-Donald et al., 2007) and has a reliability intraclass correlation of 1.00.

Vocabulary

The Picture Vocabulary (Vocabulario de dibujos) subtest of the Woodcock Muñoz Language Survey-Revised Normative Update (WMLS-R) (Schrank et al., 2010) was used to assess children's vocabulary. This subtest of the WMLS-R measures vocabulary and verbal ability in English and Spanish. Children name a series of stimulus pictures, which are arranged from familiar to not familiar. The reliability of this subtest is 0.91.

Results

Descriptive Statistics

Descriptive analyses and aims 1 and 2 were conducted using SPSS version 26 (George & Mallery, 2005). Overall teachers used more utterances discussing practices (M = 218.72, SD = 121.97) than core ideas (M = 94.85, SD = 87.82), $t(410) = -5.67$, $p < .001$. Zero-order correlations and descriptive statistics for child and teacher level variables are reported in Table 3. All child-level academic outcomes (i.e., math, science, EF, and vocabulary) were positively correlated with one another. Age was also positively associated with all of the children's academic outcomes. Sex was only significantly associated with vocabulary, where girls scored higher than boys. Dominant language was associated with children's math and science scores, where English dominant children scored higher on these assessments than Spanish dominant children. There was a weak positive correlation between teachers' documenting, and children's math scores ($R^2 = .02$). Making predictions was negatively associated with children's science scores ($R^2 = .01$). Developing and using models was positively related to children's EF scores, where earth and space science was negatively related to children's EF scores ($R^2 = .02$).

Many of the practices were positively associated with one another. For example, planning and carrying out investigations was positively associated with analyzing and interpreting data, asking questions and defining problems, constructing explanations, and developing and using models. Conversely, the core ideas tended to be negatively associated, perhaps because teachers focused on one content topic as opposed to discussing multiple topics. For example, earth and space science was negatively associated with all other core ideas. There were significant positive associations between words teachers used during practices in English and words used during core ideas used in English ($R^2 = .12$). The relation between words used in Spanish during practices and core ideas was also positive ($R^2 = .44$). Spanish and English words used during practices were negatively associated ($R^2 = .19$).

Description of Science in Majority Dual Language Learning Head Start Classrooms

Science Lessons

Physical science lessons were most frequently taught (50.00%) followed by life science (23.50%), earth and space science (17.60%), and engineering and technology/math (8.80%) (See Table 4). Making observations was the most frequently used practice, while developing and using models was the least

Table 3. Child and teacher level descriptive statistics and correlations

Underline	*N*	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Math	320	11.46	3.74	-																							
2. Science	307	.03	.87	.48***	-																						
3. Executive Function	324	24.71	33.78	.44***	.44***	-																					
4. Vocabulary	316	439.14	18.97	.42***	.52***	.40***	-																				
5. Age	327	49.28	6.69	.45***	.49***	.44***	.42***	-																			
6. Sex (boy = 1)	378	.52	.50	.04	-.08	-.09	-.14*	.03	-																		
7. Dominant Language (English dominant = 1)	411	.32	.47	.21***	.25***	.11	.05	.16**	.08	-																	
8. Analyzing and Interpreting Data	411	20.00	18.01	-.06	-.07	-.01	.03	-.08	.01	.01	-																
9. Asking questions and defining problems	411	.91	1.08	.05	.04	.04	.04	-.07	.04	.04	.27***	-															
10. Constructing Explanations	411	5.91	9.78	-.05	-.05	-.01	-.02	-.20***	.03	.04	.35***	.28***	-														
11. Developing and Using Models	411	1.56	3.96	-.03	-.02	.13*	.03	.05	.01	-.02	-.10*	-.17**	-.13*	-													
12. Documenting	411	9.21	14.24	.13*	.08	.03	.10	.09	.04	.03	.10	.39***	.05	-.19***	-												
13. Making Predictions	411	13.26	18.16	-.04	-.11*	-.02	-.02	-.05	.06	-.10	.27***	.08	.19***	-.26***	.39***	-											
14. Making Observations	411	27.12	27.70	.05	-.03	.08	-.01	-.05	.06	-.07	-.16**	-.03	-.03	-.03	.23***	.54***	-										
15. Planning and Carrying out Investigations	411	27.97	21.73	-.06	-.03	.08	.03	-.06	.06	.01	.35***	.23***	.23***	.19***	-.18***	.02	-.10*	-									
16. Using Math and Computational Thinking	411	18.18	22.40	-.06	-.10	-.09	-.03	-.20***	.11*	-.01	.34***	.25***	.30***	.08	-.14**	.06	-.07	.58***	-								
17. Earth and Space Science	411	8.82	19.60	-.07	-.10	-.13*	-.03	-.18**	.08	-.05	-.05	-.16**	.24***	-.10*	.19***	.05	-.05	.03	.10*	-							
18. Engineering and Technology	411	1.68	3.68	-.08	-.09	-.04	-.04	-.10	.06	-.04	-.11*	-.16**	.01	.48***	-.05	-.08	.07	.19***	.39***	.41***	-						
19. Life Science	411	26.53	40.00	.07	.02	.06	-.04	.01	.04	-.03	-.40***	.11*	-.16**	-.12*	.18***	.29***	.63***	-.16**	-.11*	-.20***	-.04	-					
20. Physical Science	411	7.15	11.26	.04	.09	.07	.05	.01	-.01	.04	.19***	.20***	.26***	-.15**	-.01	.02	.22***	.03	.01	-.10*	.06	-.19***	-				
21. Math	411	.87	3.34	0.03	.02	.09	.05	.01	.02	-.01	-.14**	-.18***	-.15**	.77***	-.16**	-.22***	-.06	.02	.01	-.12*	.25***	-.16**	-.12*	-			
22. Amount of English used during practices	411	52.54	39.27	.08	.05	-.02	.07	.13*	-.05	.04	.16**	-.32***	-.44***	.06	.01	-.16**	-.19***	-.20***	-.22***	-.16**	-.15**	-.33***	.12*	.27***	-		
23. Amount of Spanish used during practices	411	47.46	39.27	-.08	-.05	.02	-.07	-.13*	.05	-.04	-.16**	.32***	.44***	-.06	-.01	.16**	.19***	.20***	.22***	.16**	.15**	.33***	-.12*	-.27***	-1.00***	-	
24. Amount of English used during core ideas	411	46.84	37.34	.11	.05	-.03	.03	.14*	-.01	.07	.15**	-.25***	-.43***	.07	.06	-.15**	-.17***	-.05	.03	-.10*	.03	-.17**	.08	.27***	.85***	-.85***	-
25. Amount of Spanish used during core ideas	411	53.16	37.34	-.11	-.05	.03	-.03	-.14*	.01	-.07	-.15**	.25***	.43***	-.07	-.06	.15**	.17***	.05	-.03	.10*	-.03	.17**	-.08	-.27***	-.85***	.85***	-1.00***

Note. Means and standard deviations are reported as raw values. Vocabulary is reported as a W Score. Practices and core ideas are totals from across all contexts.

Table 4. Descriptions of science lessons by core idea, topic, and materials

Core Idea	Topic	Materials
Earth and Space Science	Blowing/Wind	Straws, blue water, plates
	Rain	Plastic cups, water, sponges, dropper, plastic syringes, bottom half of plastic bottle
	Wind	Piece of paper, wooden blocks, feathers, cotton balls, writing utensils
	Planet Earth	Worksheet activity, pencils, colors, scissors
	Volcanoes	Volcano label, 3D box with dinosaur models, plastic sheet to protect table, 3 empty water bottles, 2 bottles of vinegar, baking soda, dawn dish detergent, food coloring, 2 brown cones, spoon, sheet of paper for use as cone, dinosaur toys
	Volcanoes	Baking soda, vinegar, dish soap, funnel, empty water bottle, color food dye, bowl, sand
Life Science	Eggs	Eggs (one boiled, one not boiled), chart, chart paper, balance, scale, water bin
	Plant Project	Beans, cups, water, cotton balls
	Plant Project	cotton balls, plastic bowls, water, seeds/beans
	Life Cycle of a Chicken	Drawings of a chicken, egg, baby chicken
	Animals	Siamese fighting fish, pictures of animals, a shell, plastic animal toys
	Plants (Tomatoes)	What tomatoes need to grow, paper and markers
	Living and Non-living	plants, trays, various objects
	Germs	Microscope, balloons, sink (water, soap, paper towels)
Engineering and Technology/Math	Counting and Measuring	White sheet, crayons, counting blocks, children's hands
	Shapes and Lines	Shapes made from horizontal and vertical lines (squares and triangle), paper, markers, scissors
	3D Shapes	Markers, scissors, paper plates, glue
Physical Science	Sink or Float	Tub of water, wooden blocks, paper clips, rocks, rubber duck, boat, sponge
	Sink or Float	Tub of water, chart, crayon, foam block, shell, cork, pencil, wooden block, ball, paper clip, rock
	Sink or Float	Tub of water, a coin, scissors, paper clip, wood, feathers, rock, plastic fork, plastic football, flower
	Sink or Float	Tub of water, various knick-knacks (rocks, fuzzy pom-poms, crayon, dinosaur toy, shark toy, cork, building blocks, puzzle pieces, stick, button, straw, cardboard box piece)
	Sink or Float	Tub of water, container of various objects (basketball, pumpkin, pig, sailboats, ball, banana, cup, bat, butterfly, coin, wooden block, frying pan, feather, airplane)
	Sink or Float	Tub of water, various knick-knacks (plastic cup, tomato, bat toy, wooden blocks, plastic block, plane toy, rock, butterfly toy, basketball, seashell, banana, baby bottle)
	Sink or Float	Tub of water, foam dice, wooden block, coin, feather, scissors, chart
	Cooking (Making caterpillars)	Celery, cream cheese, raisins, knives
	Cooking (Making smoothies)	Water, lemon juice, sugar, strawberries, cups, spoons, straws
	Colors of the Rainbow	paint (rainbow colors), plastic cups, paintbrushes, paper
	Solids and Liquids	Ice, paper towel, water, spoons
	Solutions and Suspensions	Sand, water, sugar, cups, spoons
	Mixing Materials	Foam cup, sand, measuring cup, tub of water, paper, pencils, eraser
	Bubbles	Dish soap, water, cups, straws
	Magnet	Paper plates labeled 'magnetic' and 'not magnetic', magnets, rock, wooden block, magnetic letter, paper clips, clip, key chain, nail, bottle cap
	Color Mixing	paper cup, paintbrush, white paper, colors (red and yellow)
	Volcano (Acid/Base Reaction)	Empty water bottles, vinegar, baking soda, measuring spoons, cups, balloons funnel

used. The most frequently observed science lesson was on "Sink or Float" (20.59%), where teachers generally used a bin filled with water and a variety of objects to test whether items rose to the top of the water or sank to the bottom. Several teachers also conducted lessons around volcanos (8.82%). Two of these teachers focused on aspects of volcanoes related to earth and space science (i.e., volcanoes are openings in the earth's crust that erupt). The other teacher focused more on the acid/base reaction occurring in a model volcano. Science lessons discussing animals (11.76%) and plants (8.82%) were other common topics covered.

Teachers were not instructed to carry out science lessons in any particular format (e.g., in whole group or small group). However, most teachers carried out lessons in small groups with an average of 9.21 (*SD* = 2.64) children in each science lesson. During all science lessons, teachers gave children opportunities for some type of hands-on interaction with materials.

Science in Other Classroom Contexts

Not only did teachers engage in scientific practices and core ideas during science lessons, but also other contexts within the classroom. Generally, circle time was used as a time to prepare children for the rest of the day. During circle time, teachers frequently took attendance, sang songs, and assigned classroom jobs. They also discussed the weather and phonics during this time. In a few cases, circle time was used to introduce topics that teachers planned to cover in science lessons or discuss ongoing projects. One such class was engaged in an ongoing project about tomatoes. The teacher of this classroom used circle time to review what children had learned about tomatoes.

T ¿Nuestro proyecto es el tomate, verdad?
    Our project is about tomatoes, right?
C Sí.
    Yes
T Our project is the tomato.
T What did you learn about tomato?
T ¿Qué ustedes han aprendido sobre el tomate?
    What did you all learn about tomatoes?
C Sembrarlo.
    Plant it.
T Que el tomate hay que sembrarlo.
    That you have to plant tomatoes.
T ¿Sembramos el tomate?
    Do we plant tomatoes?
C No, sí, sí sí.
    No, yes, yes, yes.
C Hay que sembrar la semilla.
    You have to plant the seed.
T Hay que sembrar la semilla.
    You have to plant the seed.

During story time, several teachers chose informational books that were specifically about science topics (e.g., insects, animals, etc.). Other teachers integrated science into works of fiction. For example, one teacher read about two caterpillars who did not get along. This teacher used the book to incorporate life science facts about caterpillars and butterflies.

T And she said that uh, Clara_Caterpillar, Clara is a caterpillar?
C No.
T What is [it] now?
C A butterfly.
T Now [it] is a butterfly.
T And what butterfly have?
T How they move?
C Wings.
T Wings.

Finally, teachers and children also engaged in science during an informal setting: dramatic play. Most dramatic play areas contained dress-up clothes, dolls, and kitchen materials. Common topics of discussion around science included pretending to cook or playing doctor. While a child was pretended to be a doctor, one teacher discussed how medical tools were used.

T ¿Y tú qué estás haciendo ahí?
    What are you doing here?
T ¿Para qué se usa el estetoscopio?
    What do you use a stethoscope for?
C Para oír el corazón.
    To hear the heart.
T Para oír el corazón.
    To hear the heart.
T A ver, mira a ver si tú me puedes oír el mío.
    Let's see if you can hear mine.

Science Opportunities Throughout the Day

To examine differences in the types of practices and core ideas occurring throughout different classroom contexts, the raw number of each practice in a given context was divided by the number of minutes in each video to control for the duration (e.g., the raw number of making observations in circle time/duration of circle time). This process was also done to calculate the number of core ideas. Therefore, analyses and in-text means represent practices or core ideas/minute.

To identify whether there were differences in the number of practices/minute occurring in difference classroom contexts, a 4x9 Repeated Measures Analysis of Covariance (ANCOVA) was conducted (see Table 5 for raw means). There was a significant main effect of classroom context when controlling for teachers' highest level of education, $F(1.03, 33.05) = 12.74$, $p < .001$. In post hoc tests using Bonferroni corrections, there were significantly more practices occurring during science lessons ($M = 1.72$, $SE = .30$) than circle time ($M = .08$, $SE = .02$; $p < .001$), dramatic play ($M = .03$, $SE = .02$; $p < .001$), and story time ($M = .07$, $SE = .04$; $p < .001$). There was also a significant main effect of type of practice teachers engaged in with children, $F(1.36, 43.56) = 12.42$, $p < .001$. Examining post hoc tests, teachers analyzed and interpreted data ($M = .63$, $SE = .13$) more than asking questions ($M = .02$, $SE = .01$; $p < .01$) and constructing explanations ($M = .17$, $SE = .04$; $p < .05$). Teachers also did more planning and carrying out investigations ($M = .78$, $SE = .10$) than asking questions and defining problems ($M = .02$, $SE = .01$; $p < .001$), constructing explanations ($M = .17$, $SE = .04$; $p < .001$), developing and using models ($M = .13$, $SE = .06$; $p < .001$) and using math and computational thinking ($M = .38$, $SE = .09$; $p < .01$). Finally, teachers used math and computational thinking more than asking questions and defining problems ($M = .02$, $SE = .01$; $p < .01$).

Comparisons between practices indicated that teachers discussed and engaged children in some more than others. For example, teachers analyzed and interpreted data more frequently than asking questions and defining problems. Asking questions and defining problems was not coded for each individual question teachers asked children, but rather, larger questions about how to solve a problem (e.g., "We're going to see what type of objects sink and which ones float."). If teachers explicitly asked a question or defined a problem, it generally occurred one time at the introduction of a science lesson. Whereas when teachers analyzed and interpreted data, it occurred after an investigation had happened. Teachers often helped multiple individual children analyze their outcomes many times throughout the lesson (e.g., "Did your object sink or float?", "What about your object?", etc.). Analyzing and interpreting data also occurred more frequently than constructing explanations. Constructing explanations was defined as teachers supporting children in summarizing what they learned in a given experience (e.g., "The objects that are heavy are the ones that go to the bottom."). These tended to happen towards the end of the science lesson, if at all, and overall were used fairly infrequently across lessons.

Table 5. Descriptive statistics for practices and core ideas occurring in different classroom contexts

		Circle Time		Dramatic Play		Science Lesson		Story Time	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Scientific and engineering practices	Analyzing and Interpreting Data	0.74	2.30	0.31	1.29	33.79	32.67	0.12	0.69
	Asking Questions and Defining Problems	0.21	0.64	0.00	0.00	1.18	1.68	0.03	0.17
	Constructing Explanations	0.24	0.96	0.18	1.03	10.79	17.01	0.03	0.17
	Developing and Using Models	0.06	0.34	0.31	1.80	9.82	34.29	0.00	0.00
	Documenting	3.26	13.96	0.04	0.26	12.97	19.44	0.00	0.00
	Making Observations	4.15	9.59	2.13	6.42	41.82	55.32	4.00	9.54
	Making Predictions	2.00	10.14	0.24	0.96	21.85	26.45	1.12	4.29
	Planning and Carrying out Investigations	1.59	4.42	0.79	3.28	47.68	36.47	0.21	0.85
	Using Math and Computational thinking	1.47	6.21	0.18	0.72	21.97	28.75	1.03	2.30
Disciplinary core ideas	Earth and Space Science	2.74	6.60	1.41	7.37	10.82	31.99	2.94	7.56
	Engineering and Technology	1.32	4.46	0.49	1.44	1.65	4.31	0.44	2.57
	Life Science	16.68	29.21	4.38	9.71	19.38	37.16	19.06	32.28
	Physical Science	0.68	2.98	0.38	1.35	9.76	13.49	2.50	7.72
	Math	0.00	0.00	0.00	0.00	0.74	3.11	0.00	0.00

Note. N = 34. Means and standard deviations are reported as raw values.

Similar to analyzing and interpreting data, supporting children in planning investigations and encouraging individual children to investigate occurred frequently. For example, in a sink or float lesson, teachers asked each child one at a time to place their object into a bin of water. Thus, each child carried out their own mini-investigation while supported and encouraged by the teachers. Planning and carrying out investigations occurred more than asking questions and defining problems, constructing explanations, developing and using models, and using math and computational thinking.

A 4x5 Repeated Measures Analysis of Covariance (ANCOVA) was conducted to examine differences in the types of core ideas/minute occurring throughout different classroom settings, controlling for teachers' highest level of education. There was no significant main effect for classroom context when discussing core ideas, $F(1.36, 42.78) = 3.42$, $p > .05$. There was a significant main effect of type of core idea discussed, $F(1.12, 35.76) = 5.91$, $p < .05$. Teachers discussed more life science ($M = 1.34$, $SE = .40$) than engineering and technology ($M = .06$, $SE = .02$; $p < .05$) and math ($M = .01$, $SE = .01$; $p < .05$). Teachers also discussed more physical science ($M = .21$, $SE = .05$) than math ($M = .01$, $SE = .01$; $p < .01$).

Although there were no differences in the amount of core ideas that happened between classroom contexts, there were differences in the types of core ideas discussed. While the most common core idea taught during science lessons was physical science, teachers used more utterances throughout the day to discuss life science with children than engineering and technology and math. Most of the science lessons that were coded as engineering and technology were more math-based and had minimal engineering. For example, one teacher discussed lines for the majority of a science lesson. However, towards the end of this lesson, children began constructing shapes with these lines. Very little, if any, building occurred. Likewise, teachers also discussed physical science more than math as a core idea. Within this study, most teachers chose a science lesson that fit into the category of physical science.

Spanish and English Use when Discussing Practices and Core Ideas

A two-way Repeated Measures ANCOVA was conducted controlling for teachers' highest level of education and primary language to determine if there were differences in teachers' use of Spanish and English when discussing practices. There were no differences between teachers' use of Spanish (*M* = 51.27%, *SD* = 39.47) and English (*M* = 48.73%, *SD* = 39.47) when discussing or encouraging practices, *F*(1,30) = .17, $p > .05$. There was an interaction between teachers' primary language and the use of Spanish and English when discussing practices, *F*(1,30) = 10.93, $p < .01$. Teachers who reported that Spanish was their primary language used significantly more Spanish (*M* = 59.80, *SD* = 36.67) than teachers whose primary language was English (*M* = 3.50, *SD* = 5.01).

Another two-way Repeated Measures ANCOVA was also conducted controlling for teachers' highest level of education and primary language to determine if there were differences in teachers' use of Spanish and English when discussing core ideas. There were no differences between teachers' use of Spanish (*M* = 56.45%, *SD* = 36.57) and English (*M* = 43.55%, *SD* = 36.57) when discussing or encouraging core ideas, *F*(1,30) = .06, $p > .05$. There was an interaction between teachers' primary language and the use of Spanish and English when discussing practices, *F*(1,30) = 15.41, $p < .001$. Teachers who reported that Spanish was their primary language used significantly more Spanish (*M* = 65.21, *SD* = 32.25%) than teachers whose primary language was English (*M* = 7.37, *SD* = 11.43).

Associations Between Use of Scientific and Engineering Practices and Core Ideas and Children's Academic Outcomes

A multilevel structural equation model (MSEM) in Mplus version 8.3 (Muthén & Muthén, 2018) was used to determine if using practices and core ideas were related to children's science, math, EF, and vocabulary outcomes. To account for nesting, children were clustered within classrooms using Type = TWOLEVEL. An intercept-only model was conducted to determine the amount of variance attributable tothe classroom level in children's academic outcomes. ICCs were calculated and very little variance was explained by classroom-level factors for science (0.27%), math (2.01%), EF (3.33%), and vocabulary (0.24%).

When examining whether scientific and engineering practices used throughout the day were associated with children's science, math, EF, and vocabulary outcomes, model fit was excellent across fitindices for $X^2(2, N = 411) = 2.671, p > .05$, RMSEA= .03, CFI = 1.00, $SRMR_{within}$ =.02, and $SRMR_{between}$ =.01. When controlling for children's age, sex, and dominant language, developing and using models was positively associated with children's science, math, and EF outcomes (See Table 6). When controlling for children's age, sex, and dominant language, making observations was positively associated with children's math and EF outcomes. There were no other significant associations between the use of scientific and engineering practices and children's science, math, EF, or vocabulary outcomes.

MSEM was also used to determine if core ideas taught throughout the day were associated with children's science, math, EF, and vocabulary outcomes. Again, children were clustered within classrooms using Type = TWOLEVEL. Model fit was excellent across fit indices for $X^2(2, N = 411) = 2.63$, $p > .05$, RMSEA =.03, CFI = 1.00, $SRMR_{within}$ = .02, and $SRMR_{between}$ = .01. Controlling for age, sex, and dominant language, physical science was positively associated with children's science outcomes, while life science was positively related to children's math outcomes. Teaching math content positively predicted children's EF outcomes.

Table 6. Associations between children's academic outcomes and scientific and engineering practices and disciplinary core ideas throughout the day

	Model 1				Model 2			
	Science	Math	Executive Function	Vocab	Science	Math	Executive Function	Vocab
	b(SE)	*b(SE)*	*b(SE)*	*b(SE)*	*b(SE)*	*b(SE)*	*b(SE)*	*b(SE)*
Age	.48(.05)***	.45(.05)***	.45(.05)***	.44(.05)***	0.47(.05)***	.44(.05)***	.44(.05)***	.44(.05)***
Sex (1 = boy)	-.11(.05)*	.01(.05)	-.12(.05)*	-.16(.05)**	-0.11(.05)*	.01(.05)	-.12(.05)*	-.16(.05)**
Dominant Language (1 = English Dominant)	.17(.05)**	.13(.05)*	.05(.05)	-.02(.05)	0.18(.05)***	.14(.05)**	.05(.05)	-.01(.05)
Analyzing and Interpreting Data	-.04(.48)	-.03(38)	.13(.30)	.37(.49)	-	-	-	-
Asking Questions and Defining Problems	.14(.58)	.17(.43)	.34(.31)	-.20(.52)	-	-	-	-
Constructing Explanations	.34(.64)	.16(36)	.34(.26)	.30(.46)	-	-	-	-
Developing and Using Models	-.27(.50)	-18(.30)	.42(.21)*	.07(.34)	-	-	-	-
Documenting	.38(.65)	.47(.41)	-.13(.26)	.69(.72)~	-	-	-	-
Making Observations	.39(.71)	.78(.58)*	.62(.28)*	.35(.53)	-	-	-	-
Making Predictions	-1.04(1.50)~	-.75(.64)~	-.20(.34)	-.57(.67)	-	-	-	-
Planning and Carrying out Investigations	.17(.55)	-.24(.43)	.50(.27)~	.16(.51)	-	-	-	-
Using Math and Computational thinking	-.05(.48)	.35(.41)	-.43(.29)	.47(.60)	-	-	-	-
Earth and Space Science	-	-	-	-	.34(.74)	.59(.60)	-.02(.33)	.77(1.03)
Engineering and Technology	-	-	-	-	-.49(.97)	-.57(.60)	-.11(.31)	-.24(.58)
Life Science	-	-	-	-	.41(.86)	.88(.80)*	.56(.34)~	-.03(.49)
Physical Science	-	-	-	-	.96(1.81)*	.59(.57)	.54(.33)~	.55(.77)
Math	-	-	-	-	.59(1.13)	.63(.60)~	.59(.32)*	.59(.85)

Note. ~$p < .10$, *$p < .05$, **$p < .01$,***$p < .001$

Discussion

The current study fills a gap in the literature around the need to better understand early science education in preschool classrooms. This study is the first to examine how science is embedded in majority Spanish-English DLL Head Start classrooms and found that opportunities for science learning occurred across settings. Furthermore, it investigated the language used by teachers to discuss and engage children in science; finding that teachers used both English and Spanish when discussing practices and core ideas. Finally, the current study is the first to demonstrate relations between specific science components from the Framework for K-12 Science Education (National Research Council, 2012) and children's academic outcomes.

Describing Science in Majority DLL Classrooms

Most teachers in this study chose physical science as a core idea (50.00%) when teaching science lessons. This result differed from another study which reported that preschool teachers taught life science most frequently (56.5% of lessons) (Vitiello et al., 2019). The topics teachers tended to cover during science lessons in this study were stereotypical science topics (e.g., sink or float lessons, volcanos, plants, animals, etc.). In a study conducted by Vitiello et al. (2019), teachers chose lessons about animals and human beings most frequently. In the current study, there were instances in which teachers chose less typical science lessons, like covering topics about states of matter. For example, in one lesson on melting, a teacher implemented an actual hands-on experience. Children were given two ice cubes, asked to hold one in their hand and to put the other one in a spoon. They were then asked to see which one melted faster. The differences in topics covered could demonstrate the variation in the types of science lessons teachers feel comfortable teaching (Brenneman et al., 2009).

Results from this study also indicate that science is explored across multiple preschool contexts in majority DLL classrooms. This is consistent with prior studies (Piasta et al., 2014) where teachers promoted science learning opportunities throughout the day. When examining the practices that teachers engaged children in, the majority occurred during science lessons—demonstrating that it may be important for teachers to plan experiences that actively engage children in science.

There were differences in the amount of each practice used by teachers potentially due to the nature of the particular practice. For example, some practices like planning and carrying or carrying out investigations naturally lent themselves to be used more often. Teachers helped and encouraged multiple children to engage in planning and carrying out investigations during a given context. Conversely, some practices, like constructing explantations, occurred less frequently. The practice of constructing explanations may be more challenging for teachers to support children as it requires having a learning goal for children and being able to summarize what children have learned succinctly.

There were no differences in the total amount of core ideas that occurred in different classroom contexts, indicating that teachers in this study used contexts equally to support children's science content knowledge. However, there were differences in the amount of each type of core idea teachers taught. Life science utterances occurred more frequently than engineering and technology and math. Very little engineering occurred across contexts. Perhaps, examining other contexts that were more suited towards constructing (e.g., the block area) would uncover more discussions around engineering. Interestingly, technology was also rarely discussed. Despite young children's growing access to devices, even in lower-income communities (Griffith et al., 2019), teachers rarely discussed tools or technology. This finding was similar to Vitiello and colleagues (2019), who reported that teachers rarely used science tools. Similarly, math was generally used infrequently as a core idea across classroom settings. This is consistent with a preponderance of literature in early childhood education that educators tend to focus more on literacy and language skills than science and math (Banse, 2019; Greenfield et al., 2009).

Physical science was also discussed fairly frequently across settings. Teachers were asked to conduct a science lesson and were not given specifics about what to do during the lesson. While most decided to engage in one of the four usual core ideas, some appeared more comfortable with math as a content area. This was true for only a small number of teachers. Essentially, math may have occurred less frequently than life science and physical science because teachers were specifically asked to engage in science experiences. Since science lessons are not often done explicitly in preschool settings, asking teachers to conduct science lessons might have led teachers to view the researchers as "science people" and to focus more on science while being recorded rather than topics like letter sounds.

Language Support During Science Opportunities

Consistent with a prior study, the current investigation found that teachers used Spanish to support children's learning in science (Rumper et al., 2021). This study expanded upon those findings by examining languages used to teach science in other classroom contexts, specifically examining differences in language use between practices and core ideas. Teachers used equal amounts of English and Spanish to discuss both practices and core ideas. This finding contradicts many previous studies examining the amount of Spanish used during instruction in preschool classrooms (Burchinal et al., 2012; Chang et al., 2007; Franco et al., 2019; Raikes et al., 2019; Sawyer et al., 2018), which reported that overall, teachers rarely used Spanish during instruction.

There was an interaction between Spanish use and teachers' primary language, where teachers whose primary language was Spanish used more Spanish to discuss practices and core ideas than

English. It could be that science often involves content-specific vocabulary (Guo et al., 2016; Snow, 2010), which could be easier to discuss in one's stronger language. In this study, approximately 82% of teachers reported that Spanish was their primary language. It is unclear if teachers interpreted this question to mean "primary language" as their first language or the language they used most often. In either case, however, it speaks to the high level of Spanish proficiency of the teachers in this study.

Additionally, studies examining preschool teachers' comfort in teaching science found that teachers who received professional development in science felt more comfortable teaching science (Lange et al., 2021; Maier et al., 2013). However, other studies have found that science tends to be a domain where teachers feel less comfortable supporting children than other learning domains (Blaylock, 2019; Gerde et al., 2018). Due to this lack of comfort and self-efficacy around science, they tend to teach it less. Given the strong Spanish skills and overall lack of comfort teaching preschool science in prior research, teachers may have opted to use Spanish in formal and informal science instruction because they were more comfortable doing so.

It is also possible that teachers consciously chose to scaffold children's language development in Spanish. Again, science allows opportunities for children to learn new content-specific vocabulary (Guo et al., 2016; Snow, 2010). Most children in this study were Spanish dominant at the beginning of the preschool year (71.30%). All teachers reported having some form of professional development around best practices for DLL children. Thus, teachers might have purposefully used Spanish to ensure that children could understand the practices (e.g., "I want you to make a prediction.") they were asked to engage in and the core ideas (e.g., "He stays inside of the chrysalis.") being taught.

Associations between Science Opportunities and Children's Academic Outcomes

As hypothesized, teaching science was beneficial across multiple child outcomes in the current study. When teachers engaged children in practices or doing science, children had higher academic outcomes. Specifically, making observations was positively associated with children's math and EF outcomes. This could be because making observations often included descriptions about size, weight, and shape (e.g., "How many are there?", "Is it heavy or light?", "What shape are eggs?"), which are important math skills. Making observations also required children to attend to certain aspects about objects or phenomena and describe characteristics that were not previously described by others (e.g., "She says it's white, can you tell me something else about this egg?"). Thus, making observations might boost children's attention and working memory skills. Developing and using models was positively related to children's EF skills. When teachers engaged children in developing and using models, they were also required to draw upon EF skills like cognitive flexibility. Children must consider the actual object and think about how to represent it with materials that they have. For example, if children are making a model airplane, they must think about the parts that make up actual airplanes (e.g., wings, wheels, windows, etc.). Children must then take their knowledge about this item and think critically about how to represent it with items they have (e.g., popsicle sticks, plastic bottles, etc.).

Similarly, children's academic outcomes were positively impacted by learning and discussing core ideas. Considering physical science was related to higher science outcomes, this may reflect that physical science (e.g., exploring sinking/floating, melting, etc.) is more easily translated to hands-on experiences that give real-time in-the-moment feedback allowing children to draw immediate conclusions. In contrast, other areas, like life science, could be more difficult to provide hands-on experiences with real-time feedback. For example, several classrooms discussed plants, which usually take weeks to grow.

Likewise, animals and germs were other topics discussed. Teachers showed pictures of animals and brought in eggs; however, life science tended to lack the hands-on component, which may be important for engaging young children in learning opportunities (Zacharia et al., 2012). This might indicate that other science core ideas like engineering and technology, a prime area for immediate hands-on feedback (e.g., challenging children to build a sturdy tower), could be ideal for early science learning. However, given that few teachers in this study engaged in that domain, more research is needed to understand the role of immediate feedback in hands-on learning.

Though life science was not related to children's science achievement, it was positively associated with math outcomes. Much discussion around life science included making observations and using math. For example, teachers would say, "How many eyes do we have?" or "How many legs does this zebra have? Let's count", which may explain why teachers' discussion of life science was related to children's math scores.

Additionally, teaching math as a content area was associated with children's EF skills. This finding is consistent with prior studies (Clements et al., 2016; Daubert & Ramani, 2019; Harvey & Miller, 2017) demonstrating a relation between children's math and EF skills. This could be because math learning requires foundational skills that are critical to children's EF (Blair et al., 2008; Geary, 2010). For instance, if a teacher asks children to add two numbers together, they must consider multiple strategies (i.e., cognitive flexibility), hold mental representations of multiple values (i.e., working memory), and inhibit impulses to recite an automatized count list (i.e., inhibition) (McKinnon & Blair, 2019). Thus, if teachers incorporate more math into their classrooms, it may be a content area that has the potential to directly support children's EF growth.

Taken together, these findings indicate that science is a critical domain to support other learning domains. Overall engagement in science education may be effective because it aligns with the 6C's (Hirsh-Pasek et al., 2020; Weisberg et al., 2016). The 6Cs, *Collaboration, Communication, Critical Thinking, Creative Innovation, Confidence,* and *Content*, are a framework for creating a successful learning environment. In considering this framework, science exploration, both formal and informal, offers the possibility for deep engagement in each of the skills. For example, when considering children working on structures in the block area with peers, children can *Collaborate* and *Communicate* in working towards a shared goal (e.g., build a tall stable tower, get a marble to go down a complex ramp structure, etc.). This experience also engages children's *Critical thinking skills* and *Creative innovation*. Children attempting to get a marble to go down then up a ramp structure have to make sure the marble gets enough velocity from the place where it is dropped to get back up the other ramp. *Critical thinking* and *Creative innovation* are engaged when children are required to test different ramp angles (i.e., cognitive flexibility) and to recall which solutions that they have already tested (i.e., working memory and attention). Those 'Aha! moments' contained in science experiences build children's confidence in their ability to solve problems and learn new information. Finally, *Content* is naturally present in the core ideas. In the block area, this would be "Engineering and Technology". Given the multitude of skills that children can build through science experiences, it follows that when more science opportunities occur, children have higher academic outcomes.

Lack of Associations between Science Opportunities and Academic Outcomes

While some practices and core ideas that teachers employed were associated with children's academic outcomes, many were not. It was hypothesized that practices like analyzing and interpreting data, making observations, making predictions, and core ideas overall, should relate to children's science outcomes. These practices, in particular, would align with the format of questions present in the Lens on Science and Enfoque en Ciencia assessments. For example, items in the assessment ask children to predict where a car will be after it rolls down a ramp. However, practices did not relate to children's science outcomes. The lack of associations to science outcomes is similar to findings in prior studies examining science teaching in kindergarten classrooms (Saçkes et al., 2011; Saçkes et al., 2013). These studies found that while science teaching opportunities did not relate to children's science outcomes, other factors like children's motivation did (Saçkes et al., 2011; Saçkes et al., 2013).

Additionally, practices like making observations, and using content-specific vocabulary around core ideas would seemingly relate to children's vocabulary. However, this was not the case. Interestingly, there were no significant associations between teachers' use of practices and children's vocabulary and science scores. This contradicted prior studies examining science teaching, which found associations to children's vocabulary. Finally, almost all science practices were expected to relate to children's EF but did not in the current study.

It is possible that the measures of science, vocabulary, and EF were too broad and not specifically tailored to the types of science and vocabulary that children were learning in their classrooms. Classrooms in this study were not in any ongoing interventions. Additionally, several of the articles present in the synthesis by Guo et al. (2016) discuss measures targeted towards gauging specific vocabulary associated with the interventions, as opposed to using standardized assessments that capture a wide range of vocabulary terms. The same might be true of the science assessment used in the current study. The assessment used covers a variety of early science practices and core ideas (Kook & Greenfield, 2021). Furthermore, the EF measure was also not context-specific and was more a measure of children's inhibition skills. Honing the academic assessments to better align with the practices and core ideas children are learning could uncover more direct relations to these outcomes.

Implications

Findings from this study hold implications for classroom practice and future research around early science interventions and professional development. Regarding teacher practice, most scientific and engineering practices were observed during an actual science lesson indicating that to boost active engagement around science, it may be important to support teachers in creating intentional, planned experiences. Additionally, it could suggest that teachers require training to see the science in other everyday contexts. Conversely, there were no differences in the number of core ideas occurring across classroom settings. This indicates that teachers may view all contexts as opportunities to discuss different science content.

For early science interventions and professional development, this study indicates that Head Start teachers are engaging in science across preschool contexts, demonstrating that there is a strong foundation on which to build teachers' pedagogical content knowledge in this area. Given the opportunities already occurring during story time, teachers could use a mix of informational and fiction books to more intentionally incorporate science learning opportunities into this context. During circle time, interventions could encourage teachers to infuse more science into discussions around the weather. When teaching phonics and letters, interventions could ask teachers to use words related to ongoing science projects (e.g., writing and sounding out the word "tomato" if children are learning about tomatoes). Circle time also appeared to be an important context for preparing children for the day. In this area, interventions might consider having teachers ask children what they already know about a specific science topic. Finally, in the dramatic play area, teachers could add more materials that spark discussions around science (e.g., more doctor-related materials, a variety of kitchen items with different functions, etc.). Teachers could also hold more nuanced conversations about cooking different foods or (e.g., "How is the plastic fruit different from fruit that you eat at home?" or "When daddy cooks real eggs, how do they change?").

From a programmatic standpoint, Head Start supports the use of children's home language in majority DLL classrooms *(*Head Start Program Performance Standards, 2018*)*. The current study joins the corpus of literature around teachers' language use in Head Start (Burchinal et al., 2012; Chang et al., 2007; Franco et al., 2019; Raikes et al., 2019; Sawyer et al., 2018) but offers a perspective from a sample where most teachers reported speaking children's home language at least a little. The current study demonstrates that contexts do exist where teachers provide language support for DLL children and show some of the factors that could impact home language use in the classroom (e.g., teachers' language abilities). This could be useful in cultural contexts where teachers have similar demographic characteristics with children; however, not all Head Start classrooms have access to bilingual teachers. Thus, there is a need to identify malleable factors which could support DLL children's science learning in both of their languages (e.g., inviting parents the classroom to help out during science experiences, asking parents to send pictures of science happening at home, and to discuss them with children in the home language, etc.).

Limitations and Future Directions

While the current study has made important contributions to the literature on early science education and support of DLL children, there are several limitations. First, this study examined two important components of the K-12 Science Framework for education (Greenfield et al., 2017; National Research Council, 2012), namely practices and core ideas. However, there is a need for future studies to examine how teachers' incorporation of crosscutting concepts might affect academic outcomes. Crosscutting concepts are critical for understanding big picture ideas about how the world works and support children's learning across domains. Future studies examining science education within preschool classrooms should include crosscutting concepts in their analyses.

Additionally, the current study did not examine the quality of the practices and core ideas that teachers used. Future studies should measure teacher pedagogy or classroom quality during science opportunities. For example, researchers should seek to understand if guided play rather than direct instruction could be a better format for supporting early science learning. This could also be done by investigating the global classroom quality or using science observation tools (Vitiello et al., 2019). One study found that during science lessons teachers had higher levels of instructional support during science lessons than other areas of the classroom (Kook & Greenfield, 2021). However, another found that teachers had lower classrom quality during science (Gerde et al., 2018). Given these differences, more research is needed to understand the relation between science classroom instructional quality and children's academic outcomes.

Additionally, this study only examined children's academic outcomes in their dominant language. Since DLL children are learning two languages, it may be important for future studies to determine how science teaching might impact DLL children's total scores or conceptual scores (Core et al., 2013; Gross et al., 2014). Finally, studies investigating science in a preschool setting should also include more classrooms across multiple time points in their analyses. The current study had several trend-level associations (i.e., $p < .10$), with a larger sample size these might or might not become significant.

Conclusions

Recent national calls for attention to early science education and equity in learning have spurred an emerging body of research (NAEYC, 2019; Office of the Press Secretary, 2016). To meet these demands it is imperative that researchers and practitioners identify and support opportunities for science learning across contexts. Furthermore, especially for linguistically diverse learners, language-specific supports should be incorporated into science learning to ensure that children build foundational science skills. Moving forward, based on compounding evidence that science is a learning domain that can support other learning areas, there is a need to prepare teachers to engage in high-quality early science interactions.

Declarations

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Appendix A

Scientific and Engineering Practices[1]

*Scientific practices are the **behaviors** that scientists engage in to explore and develop knowledge.*
*Are children engaging in investigations? What are teachers and children **doing**?*

Codes	Description	Key words\Examples
Making Observations	Observing and describing is coded if teachers use, or prompt children to use their senses or tools for observation to collect information about their world (e.g., using their hands to feel ifa rock is smooth or rough; examining a caterpillar with a magnifying glass). The teacher… • observes and/or describes something related to science learning. • encourages children to observe and describe something that is related to sciencelearning. • provides language to label something that a child is observing and/or describingrelated to science learning.	Example: T Un caracol. *A snail.* T ¿Cómo será? *What's it like?* T Tóquenlo. *Touch it.* T ¿Duro? *Hard?* T ¿Igual que la semilla? *Same as the seed?*
Asking questions and defining problems	Asking questions and defining problems is coded if teachers or children identify somethingthat needs a solution. Science begins with a question about a phenomenon such as "What happened to my plant? Why are the petals falling off? Or "What's inside of a ball?"). Engineering begins with a problem that needs to be solved (such as "How can I keep my marble from rolling across the room and under the furniture?") The question asked or theproblem identified can lead to an investigation of answers or solutions to the problem. The teacher • asks questions or identifies problems related to science learning and/or identifyinga problem related to science learning. • points out/labels when a child asks a question or is curious or wondering about something, or has identified a problem related to science learning, • encourages a child to ask a question or identify a problem related to sciencelearning.	Example: T Ok before we paint we are gonna see how we can make colors with two colors. T What colors is gonna make, what coloris gonna be made, ok?
Making predictions	Making predictions should be coded when teachers and children use knowledge fromobservations and prior experiences to make an informed hypothesis (e.g., "This rock isheavy. I think it will sink in the water"). The teacher… • makes a prediction related to science learning. • labels or repeats a child's prediction related to science learning. • encourages a child to make a prediction related to science learning.	Example 1: T A baby chicken. T Ok, that's a good prediction. T Now let's see for egg number two. T What do you think is inside egg number two? Example 2:

	Note: A prediction is different from an explanation because it is about what they **think** might happen preceding an experiment.	T ¿Tú creas que se hunde? *You think it will sink?*
Developing and using models	Developing and using models should be coded if teachers help children mentally and physically represent real world phenomena to develop and deepen their understanding (e.g.,drawing a house and building it in the block center). The teacher… • labels a child's development or use of a model related to science learning and/orconnects a child's drawing or sculpture to something in the real-world • encourages children to develop and use a model related to science learning and/orencourage the child to make a connection between a drawing or sculpture and something in the real-world Note: This should only be coded in the context of **creating a representation** of something. Simply asking children to make representational art or asking children what they have created in the art center does not constitute Developing and using models. It must be clearthat the art is being done to deepen and extend children's STE learning. Evidence for this comes from the conversation with children.	Example: (Teacher uses cotton balls and water to simulate precipitation) T Todos van a tener una nubecita. *Everybody will have a small cloud.* T Miren, miren mi nube que esta llenitade agua. *Look, look my cloud is filled with water.* T Miren lo que le está pasando. *Look at what is happening.* T ¿Qué está haciendo? *What is it doing?*
Planning and carrying out investigations	Should be coded if teachers support children in organizing and implementing a procedure totest a hypothesis to seek an answer to a question, or test a hypothesis (e.g., rolling marbles down ramps of varying inclines to see which one goes faster). The teacher… • models planning and investigating for children related to science learning • labels a child's planning and investigating related to science learning. • encourages children to plan and investigate related to science learning.	Example: T Cada uno va a tener dos bloques de hielo. *Each one of you will have two blocks of ice.* T Y lo que quiero que hagan, cuando todos tienen los bloque* de hielo> *And what I want you to do, whenall of you have your blocks of ice>* T Primero se los voy a poner en su manoy después van a poner uno en una cuchara. *First, you will put them on your hand and then you will put one ona spoon.* T Y vamos a ver lo que derrite más rápido. *And we're going to see which melts fastest.*

Using math and computational thinking	Using math and computational thinking should be coded if teachers support children in using mathematics to quantify and describe their world (e.g., measuring the height of twoplants and deciding which one is taller). The teacher: • uses math and computational thinking related to science learning. labels when a child uses math or computational thinking related to science learning. • encourages children to use math and computational thinking related to sciencelearning • Note: Should not be counted if it lacks context (e.g., T The next morning at nine when they opened the zoo, the seals were swimming and Edward was too.)	Example 1: T Tú lo coges y él va medir dos cucharadas. *You take it and he will measure two tablespoons.* T Two tablespoons. T ¿Eh, X esto es una cucharada, this isone tablespoon. *Eh, X, this is one tablespoon?* Example 2: T To see the graph.T How many float? T One, two, three, four, five.T How many sink? T One, two, three, four, five.
Documenting	Documenting should be coded if teachers support children in recording and organizing, data(e.g., drawing pictures to show which objects “sink” or “float” during an experiment). The teacher • documenting data for children by sorting, taking photos, making charts, etc. that isrelated to science learning. • labels children’s documenting by using the word “document” or reminding children why they are drawing, labeling, making a chart, etc. related to sciencelearning. • encourages children to document data (e.g., draw, sort, make a chart, etc.)	Example: T And your hand, ok. T Lo que quiero es que en este papel me documenten lo que ustedes hicieron. *What I want is for you all to documentwhat you made.* T ¿Y el hielo que estaba en la mano quele pasó? *What happened to the ice that was inyour hand?*

Analyzing and interpreting data	Analyzing and interpreting data should be coded if a teacher asks children to make sense ofdata (e.g., making comparisons). The teacher… • encourages children to analyze and/or interpret data • analyzing and/or interpreting data related to science learning. • labels when a child is analyzing and/or interpreting data Note: This code should typically be used after an experiment or after the teacher and child have manipulated something. If it precedes an activity, then it will probably be "Observingand describing"	Example 1: T Ok miren lo que descubrió ella. *Ok look what she discovered.* T Que el hielo que ella tenía en su manose descongeló primero que el que ella tenía en la cuchara. *That the ice that she had in her hand melted before the ice she had in the spoon.* Example 2: T What was floating? T The dice, the wooden block, the straw,the feather, and the foam block. T Five things. T And what sunk? T The penny, the key, the scissors, and the crayon. T So more things were floating.
Constructing explanations and designing solutions	Constructing explanations and designing solutions should be coded when teachers supportchildren in interpreting data to generate evidence-based answers to their questions and design solutions to problems (e.g., "I know spiders are alive because they eat"). The teacher: • constructs explanations and/or designs solutions related to science learning • labels when children explain or design a solution related to science learning • encourages children to explain and/or design solutions related to science learning. Note: This code tends to happen after analyzing and interpreting data. It is a sort of a summary about what was done and what was learned as a result of something. It can also bea teacher prompting a child's knowledge (e.g., How do you know that?)	Example 1: T ¿Ya después que tenemos todo esto aquí adentro, ¿qué podemos decir nosotros de lo que se hunde o de lo queflota? *After we have all of them inside, what canwe tell about what sinks and what floats?* T A ver. *Let's see.* T ¿Por qué flota? *Why does it float?* Example 2: T The sand go down already, becausethe sand is not like the sugar. T It's another material, right? T It doesn't dissolve in the water.

[1] Adapted from the Early Science Framework (Greenfield et al., 2017) and the Framework for K-12 Science Education (National Research Council, 2012).

Disciplinary Core Ideas[1]
(Greenfield et al., 2017; National Research Council, 2012)

Disciplinary core ideas are the content that provide a context for engaging in practices and developing an understanding of crosscutting concepts.
*Are children **learning science facts**?*

Codes	Description	Key words\Examples
Physical Science	*Physical Science should be coded if teachers and children discuss facts about the following:* - ***Matter and its interactions** …learning about what things are made of and how they affect each other (e.g., liquid can be made solid by freezing).* - ***Motion and stability** …learning about how things move or stay where they are (e.g., kicking a ball makes it roll).* - ***Energy** …learning about energy sources that power our world (e.g., animals eat food for energy).* - ***Light and sound waves and their applications** …learning about how light and sound move and its impact on the environment (e.g., light waves can be blocked by certain objects, creating a shadow).*	Example 1: T1 Is the baking_soda a solid or liquid? Example 2: T Magnets. T Remember, magnetic are X. T They stick or they are pull. T Or they attract to the magnet, ok? T That's our magnetic. T And non-magnetic is when the object is what?
Life Science	*Life Science should be coded if teachers and children discuss facts about the following:* - ***From molecules to organisms**…learning about the needs and characteristics of living things (e.g., roots help trees absorb water).* - ***Ecosystems** …learning about how living things interact and use their environment to survive (e.g., birds use twigs from their surroundings to build nests).* - ***Heredity and traits** …learning that living things have features that are similar and/or different from each other (e.g., all dogs have fur and four legs, but some are small and others are big).* - ***Biological Evolution**…learning about how living things evolve and change (e.g., lizards resemble dinosaurs).*	Example 1: T Hay tres cosas importantes que la semilla o la planta necesita para crecer. *There are three important things that the water or the plant needs to grow.* T Agua, como dijo él, la lluvia, que lo podemos dibujar en una columna. *Water, like he said, the rain that we can draw in a column.* T El sol o los rayos del sol, que la podemos dibujar en la otra columna, y lo que dijo ella, muy importante. *The sun or the rays of the sun, that we can draw in another column, and what she said, very important.* T ¿Qué cosa es en la otra columna? *What is in the other column?* T La tierra. *The earth.* Example 2: T Si tú vas al doctor, el doctor chequea tu garganta, tu sangre. *If you go to the doctor, the doctor will check your throat, your blood.*

		T Y poniendo algo aquí con un poquitito de sangre, puede ver si tienes gérmenes. *And putting something here with a bit of blood, He can see if you have germs.* T Tienes virus o tiene bacteria que producen enfermedades. *Or if you have a virus or bacteria that produces illnesses.*
Earth and Space Science	*Earth and Space Science should be coded if teachers and children discuss facts about the following:* • **Earth's place in the universe** *…learning about the patterns, cycles, and movement of the earth, sun, moon, and stars (e.g., the sun is visible during the day and the moon is best visible during the night).* • **Earth's systems** *…learning about the natural systems on earth and how they shape it (e.g., a squirrel lives in a place with lots of trees because it uses trees for shelter and food).* • **Earth and human activity***…learning about how people and the world interact (e.g., humans need water, air, and resources form the land to live).*	Example 1: T Aquí, en estos lugares, como por ejemplo en el Polo, la temperatura es muy fría. *In these places, for example the Poles, the temperature is very cold.* T Y ahí el agua se cae en forma de nieve. *And there, the water falls down in the form of snow.* T Pero aquí en nuestra ciudad cae en forma de líquido y eso es lo que nosotros vamos, y eso es lo que nosotros vamos a hacer. *But here in our city water falls down in the form of liquid and this is what we, and this is what we are going to do.* Example 2: T ¿Y cómo el agua sube a las nubes, de dónde el agua sube de las nubes? *And how does the water rise to the clouds, from where does the water rise to the clouds?* T ¿Quién le da el agua a las nubes? *Who gives water to the clouds?*

Engineering and Technology	*Engineering and Technology should be coded if teachers and children discuss facts about the following:* • **Engineering Design**…*learning about how people design tools to help them answer questions and solve problems in everyday life (e.g., a child uses a wood plank to cross a small stream on a nature walk).* • **Links among engineering, technology, science, and society**…*learning about how people use tools to help them answer questions and solve problems in everyday life (e.g., using a magnifying glass to observe the parts of a leaf).*	Example 1: T What is this? T Ruler. T This ruler is going to help us make lines. Example 2: T Microscope. T ¿Y para qué se usa? *What is it used for?*
Math	Math should be coded if teachers and children discuss facts about the following: • Shapes, sizes, sorting, patterning, and counting. *Note: This specifically differs from the practice, "using math and computational thinking" in that the content focuses on math as a learning goal and not an action.*	Example 1: T You remember that yesterday we talking when we learned about the three-dimensional geometric solids, yeah? T And you remember what is the geometric solid and the three-dimensional? T A ball? T A cylinder?

[1] Adapted from the Early Science Framework (Greenfield et al., 2017) and the Framework for K-12 Science Education (National Research Council, 2012).

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Research Article

Science starts early: A literature review examining the influence of early childhood teachers' perceptions of gender on teaching practices

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Abstract: Women are underrepresented in science fields as compared to men and although much research has been dedicated to understanding this disparity, most has been conducted on older aged children. However, this excludes the youngest and arguably most impressionable group of students: preschoolers. This study reviewed the literature to investigate how early childhood teachers' perceptions of gender influence their teaching practices. Qualitative analysis and coding of 31 articles resulted in five main categories: *Teacher Perception, Curriculum, Teacher Interactions, Gender Identity*, and *Social Standing*. Results are discussed in the context of early childhood science teaching practices to better understand the role of the teacher and gender bias in young children's preschool science experiences and how it may impact their future science interests.

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Early childhood; Science; Preschool; Gender

Introduction

It is widely known that girls and women are underrepresented in science fields. One explanation for the noted discrepancy are gender socialization processes and societal attitudes that encourage traditional gender roles (Eccles et al., 1993; Eccles, 2007; Haworth et al., 2009; Leibham et al., 2013). Gender roles are believed to be socially constructed through values and beliefs present in relationships, society, and institutions (Davies, 2003). Gender roles are acquired early in life and have the potential to influence both males and females (Bigler & Liben, 2006).

Developmental Intergroup Theory (Bigler & Liben, 2006) aims to explain children's acquisition of stereotype and prejudice by proposing that "biases may be largely under environmental control and thus might be shaped via educational, social, and legal policies" (p.162). This idea is supported by a study of interactions in the home environment, finding that mothers' perceptions of their child's math abilities predicted child beliefs about their math ability (Gunderson et al., 2012). The family context has been a focus of research in developing gender roles. A study analyzing the conversations of parents and children during science-related tasks indicated that parents perceived science activities as more difficult and less interesting for their daughters than their sons (Tenenbaum & Leaper, 2003). As a result, interactions with daughters and sons differed, indicating that differential treatment in regards to science occurs in the home environment. Further, research indicates that opportunities for science learning also varies, with parents of young boys ages 4 to 7 years old reporting more science-related opportunities for their child than parents of young girls of the same age (Alexander et al., 2012). Yet these differences are not confined to the home environment. In a study of interactions between parents and their children at a museum exhibit, researchers found that boys were three times more likely to receive science explanations from their parents than girls despite equal amounts of conversation (Crowley et al., 2001).

Likewise, it is conceivable that early childhood teachers, knowingly or unknowingly, exhibit similar gender bias in their interactions which may impact the children in their care. Teachers are largely in control of the quality of the classroom. This is particularly noteworthy because for young children, preschool is the

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first experience in a formal educational setting and sets the stage for development, future interests, and learning. Therefore, it is important to understand early childhood teacher's attitudes and perceptions of gender and how it may influence teacher practices. Teachers may explicitly or implicitly demonstrate gender biased views or stereotypes that influence their interactions, management, and pedagogical decisions in the classroom. Exposing young children to early gender stereotypes has been shown to influence children's long-term interests and ideas about intelligence (Bian et al., 2017). The present study systematically examines the literature using the research question, *How do early childhood teachers perceive gender and how does this influence their teaching practices?*

Developmental Intergroup Theory

This research is guided by Bigler & Liben's (2006) Developmental Intergroup Theory (DIT), an approach to understanding and explaining how children develop stereotyping and prejudice. Other theories have attempted to explain children's acquisition of biases, DIT furthers those understandings by describing why some traits and not others become the focus of bias (Bigler & Liben, 2006, 2007). Many variations of human dimensions exist, such as handedness, skin color, gender, and eye color; yet not all of these features are prominent factors in stereotyping and prejudice. DIT addresses this difference by combining concepts from social identity intergroup theory and cognitive theories of constructivism offered by Piaget to propose that stereotypes and prejudice are attained largely through explicit and implicit biases displayed in the environment coupled with children's developing ability for categorizing salient attributes (Bigler & Liben, 2007). DIT suggests that three main processes occur for individuals when forming social stereotyping (Bigler & Liben, 2007). First, the child establishes psychological salience of attributes that differ across people. Next, children categorize individuals by salient traits which is part of a cognitive-developmental process, constructivism, in which the child attaches meanings (positive or negative, true or untrue) to the categories they have created. Finally, this results in the third process of developing stereotypes and prejudice related to salient features. Given that the purpose of this paper is to explore children's preschool experiences related to adult perceptions of gender, the first process of DIT is particularly relevant. Understanding how children are establishing psychological salience of personal attributes, which is largely based on their experiences, may provide insights on how to prevent the formation of social stereotypes and prejudice. Bigler & Liben (2007) suggest children's formation of psychological salience of attributes occurs in four ways: proportional group size, perceptual discriminability, explicit labeling and use, and implicit use. Proportional group size is relevant when working with populations that form a minority. In the case of this study, it is less important and was not a focus of my analysis as males and females make up roughly equal amounts of the population. For this study, the factors of perceptual discrimination, explicit use, and implicit use are most relevant.

Perceptual Discrimination

It is important to consider how children might be receiving messages from their environment and interactions and then subsequently shaping these messages into thoughts about their own or others gender. Perceptual discrimination refers to noticeable features, which young children tend to focus on, such as noticing hair color instead of less-noticeable handedness. Early childhood educators who intentionally draw attention to gender defining features, clothing, or traits would make gender more salient for children. While categorization is an important skill for children to learn and an almost infinite amount of ways exist for categorizing, some are more prevalent than others, such as gender. A continuous emphasis on gender categorization by a teacher may signal to children that this is an important bases for classifying people. This is significant in relation to science because children are forming ideas about their own gender and others gender which may unintentionally serve as a foundation for science-related stereotypes regarding who does and does not do science and who belongs in scientific fields. Beyond science, this raises ethical concerns for gender nonconforming children who would benefit from gender neutral language and deserve a supportive environment that respects their most authentic self. Gender nonconformity is beyond the scope of this paper, but warrants further research and consideration.

Explicit Labeling and Use

Early childhood educators may explicitly categorize gender through their daily routines and practices (playing a song during music and movement that requires girls to move in one way and boys to move in another). Educators can explicitly enforce gender roles by managing the classroom with a focus on traditional gender behavior, such as intentionally leading girls to more feminine centers in the classroom to practice gender roles such as "playing house" or "cooking." This type of explict labeling and use could draw children's attention to and reinforce stereotypes that deter children from playing outside of their perceived gender role, potentially limiting girls' play and exploration of science-focused centers.

Implicit Labeling and Use

Implicitly shaping gender stereotypes in the early childhood classrooms occurs when educators make gender unnecessarily salient (instructing a child to "Ask the man if the mail has arrived"). Another aspect would be grouping children by gender without explicitly labeling the groups but then segregating the groups. This approach shows that when groups are segregated by a feature, although the feature is not labeled, higher bias occurs (Bigler & Liben, 2007). Teachers implicit labeling has the potential to introduce or reinforce bias making it vital that teachers are aware of their own prejudice and biases related to children's gender and science.

Overall, DIT helps explain factors that may be contributing to the formation of social stereotypes and prejudice in young children. Early childhood teachers' perceptions of gender may influence their classroom teaching practices which could impact children's science learning opportunities and subsequently children's science-related interests and experiences. Thus, it is important to understand early childhood teachers' perceptions and attitudes about gender and how it influences their practices.

Literature Review

A generous amount of effort has been dedicated to studying gender inequality in science, technology, engineering, and mathematical (STEM) fields, most conducted at the middle-school, high-school, and college levels (Riegle-Crumb et al., 2012; Robinson-Cimpian et al., 2014; Wang, 2013). Even extensive reviews of the literature on girls and science are comprised largely of studies on older students, with only a handful of articles on elementary schools identified (Brotman & Moore, 2008). Unfortunately, this overlooks the youngest and arguably most impressionable population of students: preschoolers.

Findings on science achievement are at odds. In elementary school, girls show less interest in science than boys with girls' interest continuing to decline with age so that by ages 10-14 a marked difference in science attitudes by gender appears (Catsambis, 1995). Unfortunately, not only does interest wane for girls, but they perceive science as uninteresting and boring (Jones et al., 2000). Although some research indicates girls have a less positive attitude and interest in science, there is evidence that they perform equally as well or better than their male counterparts in science class (Catsambis, 1995; Greenfield, 1996; Jones et al., 2000). However, more recent literature reveals a gender gap in science achievement beginning as early as first grade (Curran & Kellogg, 2016) and persisting over time, resulting in a call for intervention at an earlier stage of development, such as preschool (Morgan et al., 2016). One area of consensus between early childhood and the science field is on the suitability of teaching science in the early years. Most agree that children have a natural curiosity of the world around them which motivates them to explore scientific concepts and topics in authentic ways. In addition, research supports science education beginning early on in life as a way to develop positive attitudes towards science, expose children to scientific concepts through language and teachable moments, and develop scientific thinking (Eshach & Fried, 2005; Morgan et al., 2016). There is increasing evidence that children's early interests (including those that are science-related) can persist over time and influence the course of learning (Alexander et al., 2012) underscoring the importance of providing early opportunities for exploring science.

The early childhood environment may be ripe for children's science exploration but barriers exist to teaching science. Teachers report lack of confidence and content knowledge (Gerde et al., 2018; Kallery & Psillos, 2001; Park et al., 2017), time (Greenfield et al., 2009; Park et al., 2017), and materials (Tu, 2006) as factors impeding science instruction in the classroom. Notably, these reasons impact both structural and process quality indicators. Structural indicators refer to a characteristic of the environment and process indicators refer to interaction between individuals (Cassidy et al., 2005). Structural and process indicators are concepts by which the quality of early childhood environments are often assessed. Barriers in both of these areas are likely to affect the amount and quality of science teaching and subsequently, children's science interest and learning. If the quality and quantity of science teaching in preschool is low for all children, it is especially detrimental for young girls who benefit when teachers foster their sustained science interest (Leibham et al., 2013). For preschool-aged girls, an intense science interest predicts a significantly higher science self-concept at 8 years old (Leibham et al., 2013). Science self-concept is defined as "an understanding of their attributes, abilities, and values" (Leibham et al., 2013) and can be constructed through daily interactions such as play (Chafel, 2003). For preschool-aged boys, early interests are not predictive of science achievement as they are for girls (Leibham et al., 2013). This underlines the importance of fostering girls' early interests in science during the preschool years.

An important component of early childhood education is the foundational relationships upon which subsequent experiences and knowledge are built. Research implicates teacher attitude as a contributing influence on developing gender stereotypes in children (Beilock et al., 2010; Robinson-Cimpian et al., 2014). Whether implicit or explicit, teachers' actions and words can convey gender bias and influence the types of activities and interests' young children develop, even shaping later career choices (Bian et al., 2017). Gender bias has the potential to negatively and inaccurately influence young children's image of themselves and their capabilities.

In summary, gender differences in preschool science experiences and science achievement are less understood than those that occur at other levels of education. Reported differences in science achievement could mean two things: girls are either as capable as boys in science but do not select science careers, or that girls' lack of interest and/or achievement is identifiable early on and persists. Either way, this warrants further investigation of classroom processes, such as teacher and child interactions in the preschool years, which have been identified as an ideal time for teaching and exploring science concepts. Science teaching is lacking, in part, because early childhood teachers feel unprepared to teach science activities (Greenfield et al., 2009). While children are naturally curious about the world around them, developing scientific reasoning skills requires both engagement and interaction around science content and materials (Gelman & Brenneman, 2012; Morris et al., 2012). Science materials, a structural component of the early childhood environment, are selected and displayed for use by classroom teachers who lack confidence in their science abilities (Greenfield et al., 2009). Teachers identify several reasons that science instruction is lacking in early childhood such as their lack of confidence and instructional time but research to date has not included teacher perceptions of gender that may also impact their interactions with children in the classroom (Greenfield et al., 2009). These perceptions may implicitly or explicitly influence both structural and process quality in the early childhood environment. A clearer understanding of how teachers' gender perceptions may influence their teaching practices and subsequently impact children's learning opportunities and experiences in the preschool classroom is needed. The purpose of this paper is to address this gap in the literature.

Method

The goal of this paper is to examine research on early childhood teachers' perceptions of gender in the classroom. I used several search strategies to identify studies. First, a discovery catalog and database ProQuest Educational Resources Information Center (ERIC), were searched using two combinations of terms: 1) *preschool teacher* and *gender;* and *2) teacher attitude, gender,* and *preschool*. This resulted in 37 articles and 31 articles, respectively. These terms were selected with a goal of including early childhood articles related to teacher perception and gender in any domain of learning. To identify articles related specifically to gender topics in education and science content in preschools, the search was narrowed to a selected set of journals (Brotman & Moore, 2008). Seven specific journals were searched that focus on science in education: *Journal of Research in Science Teaching, International Journal of Science Education, Journal of Science*

Teacher Education, Science Education, and *Research in Science Education*. A review of two other journals were also included because they are not limited to the field of science but might provide insights into the research topic: *Gender and Education* and *American Education Research Journal* (Brotman & Moore, 2008). These efforts resulted in an additional 4 articles specific to gender at the early childhood level. Lastly, a search was conducted of PsychINFO using a combination of the terms *early childhood education, teacher attitudes, teacher perceptions* and *gender.* This resulted in an additional 32 articles. In total, 104 articles were originally identified.

After reviewing the collected articles, it was apparent that several of the articles were beyond the scope of this paper and did not meet the purpose of the study. In order to address the proposed research question in a systematic way, three main inclusion criteria were established for the review. First, the article must be published in a peer reviewed journal; this eliminated doctoral dissertations, master theses, and other articles printed in news-type magazines. Second, the article must be relevant to the topic of early childhood teachers' perceptions of gender and children 6 years old and younger. Third, the article must be in English. This led to research contributions from the following countries: Australia, Canada, Denmark, Finland, Indonesia, Israel, Japan, Norway, Poland, Qatar, Spain, Sweden, Turkey, and the United States. Specific interest included the teachers' practice influencing children, teacher perceptions of gender, and teacher values about gender for children kindergarten age and younger.

Articles that were excluded from the review were those that did not meet the purpose of the research. This included studies on efforts to increase the amount of male preschool teachers employed in the early childhood field, transgender and non-binary research and trainings for early childhood teachers, the development of sexuality in preschool, parent gender perceptions and influence, and articles reporting gender differences among various academic domains or interventions. After categorizing articles using established inclusion and exclusion criteria, 27 articles were identified for review. As recommended in methodological literature, a secondary search was conducted using references lists from recent literature reviews (Fraenkel et al., 2016). This resulted in an additional four articles that met inclusion criteria. A complete summary of the final 31 articles analyzed for this review is available in Table 2.

Data Analysis

A thorough review was conducted using content analysis (Saldaña, 2015) to systemmatically examine articles for purpose, participants and setting, methodology, and major findings. Major findings were manually coded by the reported overall effect on young children. Articles that were primarily focused on teacher attitudes towards gender but did not include child outcomes made up their own category. Three articles included a child outcome based on parent perception but not teacher perception. These were removed from the final analysis. Fourteen initial codes were then combined and reduced to five overall categories that signify the findings in the literature (Saldaña, 2015). Articles were organized into established categories demonstrating the range of results in each category. Another aspect of the articles analyzed included the date of publication of the studies to identify potential patterns or trends in how this topic has been explored both recently and historically. In the sections that follow I discuss the major findings and implications related to science learning in the early childhood classroom. It is noteworthy that the articles originate from multiple countries, adding complexity to the synthesis of findings, but strengthening the emphasis on the importance of the need to understand the impact of gender on children in early childhood classrooms world-wide.

Results

The five categories that emerged from data analysis were: *Teacher Perception, Curriculum, Teacher Interactions, Gender Identity,* and *Social Standing*. Each of these categories was created by combining the initial codes (See Table 1).

Table 1. Categories and underlying codes

Teacher Perception	Curriculum	Teacher Interactions	Social Standing	Gender Identity
Teacher perception Teacher attitude Awareness	Play Opportunities for play Selection of activities Materials for play	Behavior Adult relationships Engagement with teacher Discipline	Interactions with peers Social standing	Understanding of identity

Teachers' perceptions of gender were the focus of most of the research studies (see Figure 1) and established the category *Teacher Perception*. Teachers' perceptions of how they view young children by gender provides insight into teacher thoughts and opinions but it is not possible to infer how this translates into practice and pedagogical decisions without further evidence. Studies that reported child outcomes suggest that an early childhood teacher's perception of gender influences four areas, which generated the other remaining categories: *Curriculum, Teacher Interactions, Social Standing,* and *Gender Identity* (see Figure 1).

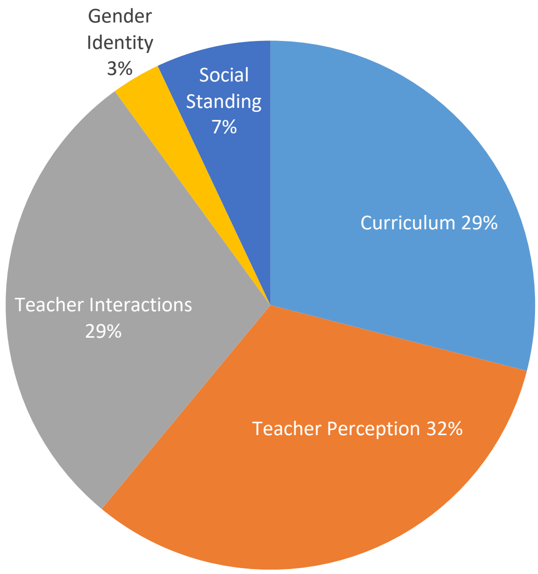

Figure 1. *Proportion of Articles by Category*

The oldest publication in the review was categorized in the *Curriculum* category; however, this category also contained recent publications as well. The *Curriculum* category includes articles related to children's learning, play, along with the materials and environment that create the curriculum. Young children's work is often considered their play and learning through play is a foundational element of early childhood education which has been studied for many years, so it is not surprising that this category contained the oldest publication. Results show that chronologically the category with the most recent publications was *Teacher Interactions*. This could in part be due to an emphasis in the field on process quality indicators and improved measures of teacher interactions.

Teacher Perceptions of Gender

Early childhood teachers' perceptions of gender were investigated through surveys, questionnaires, and semi-structured interviews (See Table 2). One of the articles in this category was a review of articles related to sexism in the context of early childhood. In that review conducted by Duke and McCarthy (2009), nine articles (39%) identified that some teachers were uncomfortable with non-stereotypical gender behavior by children and eight (26%) of the articles described ways that early childhood education programs reinforce traditional gender roles. In one study, teachers thought that gender stereotypes were reinforced through the use of children's literature and even television programming. Other articles included in this category shed light on teachers experiences, perceptions and classroom practices. For example, early childhood teachers recall playing in gender stereotypical ways in their own childhood (Sandberg & Pramling-Samuelsson, 2005). Interestingly, Erden (2004) found that although teachers reported an egalitarian view on gender, when asked whether they agreed or not with gender traditional statements such as, "girls are more emotional than boys," up to 40% of teachers agreed. This indicates that teachers perceive the genders as having traditional differences while also reporting a belief in gender equality. In the classroom, teachers who held egalitarian attitudes had also adopted egalitarian discipline styles indicating that at least in one way teacher perception is related to teacher practice (Erden, 2004). How teachers perceive appropriateness of children's behavior, especially aggression, by child gender showed differences as well. For example, female teachers differed from male teachers in their identification and ratings of children's aggression (Pellegrini et al., 2011). Male teachers identified more aggression in the classroom than their female counterparts (Pellegrini et al, 2011). In addition, one study showed that male teachers thought that a child displaying aggressive behavior would perform better and be less likely to be excluded in play (Bosacki et al., 2015).

In summary, early childhood teacher's perceptions of children's gender is influenced by the teacher's own previous experiences and their own gender. Perceptions of gender can influence the meaning that teacher's assign to children's behavior and how they respond to behavior through discipline style. While this is informative, the extent to how these perceptions influence children in the classroom is less clear.

Curriculum

In the literature addressing curriculum, a variety of qualitative and quantitative methods measuring learning and play in the classroom were used (See Table 2). Researchers examined both structural and process quality to address children's classroom experiences. Structure quality was investigated by measuring aspects of the environment such as the types of books and toys available to children as well as where in the classroom the teacher most often played. Processes of play were measured through examining the types of activities and the interactions children had with teachers in the classroom, which were investigated using observations, interviews, and focus groups. One study in this category explored the environment and culture of the classroom. Borve and Borve (2017) studied the classroom physical environment and conducted interviews with teachers and assistant teachers (15 female and 3 male) at a Kindergarten in Norway. They found that the environment was primarily designed by the female teachers, leading to an environment described by the teachers as "feminine". Areas were designed based on how teachers felt children would use the space which led to teachers creating and designing the classroom in a traditionally gendered way. For example, teachers identified boys as playing in ways that were rougher and louder and consequently, required more space. Girls, on the other hand, were thought to play in more quiet and gentle ways. This resulted in areas designed for boys taking up more space than those designed for girls. And although children occasionally crossed into all spaces, teachers thought that children used the spaces differently based on child gender. Authors suggest that spaces were not designed and set up for gender neutral play and that the intention for play impacts how children used the space. This resulted in play practices that mimicked adults' ideas of gender (Borve & Borve, 2017). Similarly, interviews with teachers during focus groups in Spain revealed gender division in areas of the classroom consistent with their views on how boys and girls play (Rodriguez et al., 2006). In these focus groups, teachers noted that they had expectations for girls' play that was mothering and nurturing and when boys played in this same caring way, some of the teachers even responded with surprise. It is important to note that while teachers voiced an expectation for gendered behavior, they did not negatively reinforce nonconforming play. In fact, they used moments of unexpected nonconforming play to talk about equity (Rodriguez et al., 2006).

Another structural component of the environment and important part of the curriculum is literature, including the books available within the classroom and those selected and read by the teacher. In a study of 618 book readings, 433 unique books were presented to children across six preschools in Sweden. Results showed that significantly fewer girls were main characters than boys (Lynch, 2016). Both teachers' and children's choices for books to read were significantly more likely to have a male main character. Gender equity in literature is deficient in preschool classrooms (Lynch, 2016). This is problematic because children may perceive girls as less important because they hold a lesser role in literature than boys. When children view less minorities, including females, in literature, they may internalize that they have less value in society (Lynch, 2016). It is important to note that teachers' selections of children's books are limited to books in publication and the lack of children's books with female main characters is largely out of their control.

Toy selection is another important aspect of play. One study conducted by Trawick-Smith and colleagues (2015) showed that teachers and parents select toys that engage boys more than girls. Researchers asked teachers and parents to nominate nine toys that they felt would benefit child development. Observations of the toys being used in the classroom indicated that child gender was an influencing factor in children's selection of toys and the quality with which it was played (Trawick-Smith et al., 2015). Results showed that when boys played with the toys, the quality play score was higher (Trawick-Smith et al., 2015). Quality was measured in seven areas: thinking and learning, problem solving, curiosity and inquiry behaviors, sustained interest, creative expression, symbolic representations, and interactions, communications, and collaborations with peers. This finding could be problematic because it indicates that teachers and parents may not select toys that can engage both genders in equally beneficial ways. Children selected items they enjoyed but their play with these toys didn't automatically result in high-quality play. Thus teachers may need to carefully consider how to enhance or scaffold play with a preferred toy. Teachers' careful observations of play should go beyond child preference and include a focus on quality of engagement.

Rodriguez and colleagues (2006) found that teachers gave children the freedom to select and engage in play without adult intervention and that it was not necessary to address gender stereotypes in the classroom because children are choosing their play preference. As mentioned earlier, teachers expected children to play in traditional gendered ways and therefore create an environment conducive to gendered play (Borve & Borve, 2017). It is also plausible that children have been socialized to play in gendered ways via media, society, and other influences and that early childhood environments perpetuate the stereotype by not disputing them. Another study found that a teacher's presence in areas of the classroom, including the science area, drew children to the area to play (Tomes, 1995).

Early childhood teachers are also responsible for planning activities. Planning is influenced by how teachers view gender roles, as shown by interviews and observations in a study of teachers and children in Australia (Chapman, 2016). Using observations of the classroom and interviews with four teachers, researchers found that teachers who held more egalitarian views on child gender and play appeared to acknowledge gender issues in the classroom and implement strategies to counter gender roles or stereotypes (Chapman, 2016). The idea that teachers perceive play differently based on child gender is not new and was supported in a study by Logue and Harvey (2010) where teachers shared their belief that boys participate in more superhero play and girls participate in more nurturing activities, such as "playing house" or "family". Teachers then self-reported stopping dramatic play almost half the time (48%) for boys and only 29% of the time for girls, and intervening in social conflict more frequently for boys than for girls. The same teachers thought that their own plans for dramatic play were more productive than children's own imaginative play (Logue & Harvey, 2010). Taken together, these findings suggest that teachers' perceptions of gender play can influence how teachers plan for play and may result in differences in how children engage in and are supported in their play.

Outside of planned activities, teachers have the opportunity to use everyday experiences as teachable moments. Granger and colleagues (2017) observed children's free play and found that teachers facilitated gender-typed activities based on the gender make-up of the group. For example, 27 female teachers in Head Start classrooms working with girls facilitated masculine and gender-neutral activities significantly more often than feminine activities. This same study found that gender-neutral activities were implemented more frequently with groups of girls than with groups composed of boys (Granger et al., 2017).

Teacher Interactions with Children

Early childhood teachers have countless interactions with children each day. Most research in this category indicates that a child's gender influences the interactions he or she has with the teacher (see Table 2). Interactions include classroom conversations, responses, directives, and engagement between the teacher and the child. For example, in-service and pre-service preschool teachers in Sweden thought "headstrong" and "disobedient" behavior from girls was less allowable than similar behaviors from boys (Hedlin & Aberg, 2018). This led to the teacher interacting in a dismissive way towards the student who was then labeled as "very troublesome" (Hedlin & Aberg, 2018). Another study showed a comparable finding when staff members at 80 kindergartens in Demark responded to gender-related dilemmas. Teachers' responses to the gender dilemmas differed by child gender, but not by teacher gender, indicating that regardless of teacher gender, teachers consistently treated boys and girls differently (Olsen & Smeplass, 2016). A similar outcome was found in a study in Indonesia, where informal and formal interviews with teachers, conversations with children, and field notes of daily classroom activities were analyzed to explore care from staff. Results indicated that teachers cared for children in stereotypical ways that likely preserved gendered behavior in children (Adriany & Warin, 2014). For example, in the annual school musical celebrating diversity and uniqueness, the female children were assigned feminine roles of flowers, fairies, and a princess; while the male children took on the role of fish. The message of respecting differences and celebrating each individual was lost in the expectation for children to perform traditional gender roles. Overall, teachers reported that cultural diversity was celebrated at the Indonesian school; however, gender was not openly addressed and traditional gender behavior was encouraged (Adriany & Warin, 2014). In a study conducted in the United States, differential treatment in four teaching practices (physical interactions between children, verbal and physical directions of body, voice control, and behavior management) contributed to gender differences in 5-year-old children in 5 preschool classrooms (Martin, 1998). Differences included how the teacher interacted with a child through restricting a child's voice, dressing-up, limiting physicality, or instructing children how to physically be with one another (Martin, 1998). Still, some hope for gender equitable interactions in preschool classrooms exists. In a large study of 342 children aged 34 – 63 months from 100 classrooms in the United States, children's positive engagement with their teachers was analyzed for associations with individual child factors (age and gender). Researchers found that neither age nor gender were significantly associated with children's positive engagement with their teachers (Vitiello et al., 2012). Notable differences from this study as compared to the older Martin (1998) study include the number of participants, the extended child age range, and the measure of engagement. In the latter study, a standardized observational assessment, the InCLASS, was used to measure interactions; whereas the former used a semi-structured observation with field notes. In summary, support exists to suggest early childhood teachers' interactions with young children are influenced in some ways by child gender.

Social Standing

The Social Standing category was created by combining studies indicating that a child's perceived popularity, relationships, or social competence was influenced by adult gender perceptions. Only two articles belong to this category (See Table 2). The purpose of the first study was to explore the impact of gender stereotyping on young children. Researchers found that teachers rated girls and boys who conformed to gender stereotypes as more likable than their non-conforming peers (Sullivan et al., 2018). In fact, teachers rated girls more likable than boys and boys were likely to experience criticism for violating gender stereotypes (Sullivan et al., 2018). One aim of the second study was to assess and compare gender differences in prosocial behavior among preschoolers in a Middle Eastern country. While gender differences in prosocial behavior are well documented, this research was unique in that it was the first in Doha, Qatar (Al-Thani & Semmar, 2017). Teachers were asked to complete a questionnaire regarding their interactions with students and observations. Findings indicated that teachers perceived boys as displaying less prosocial behaviors than girls. Significant gender differences were found in subscales of teacher preferred behavior, peer preferred behavior, and school adjustment indicating that teachers of preschool children in Doha, Qatar, rated boys as underperforming girls in social competence (Al-Thani & Semmar, 2017).

Child Gender Identity

The category of Gender Identity contained only one study, which was conducted in Japan (See Table 2). Gender identity is viewed as an individual's perception of who they are and how they characterize themselves in terms of culturally defined male and female roles (Wood & Eagly, 2015). For example, a study of private day care teachers in Tokyo was conducted over the course of one year, in which researchers observed one to two times per month for how children and teachers used the word *kawaii* (cute, lovable). Teachers used *kawaii* as an indication of gender and described girls using this term which led to girls using *kawaii* to describe or refer to themselves (Burdelski & Mitsuhashi, 2010). This research found that female, but not male, children adopted *kawaii* as part of their identity.

Table 2. Articles by category

Author(s) (Year)	**Purpose of Study**	**Participants and Setting**	**Method**	**Major Findings**
Curriculum				
Borve, H.E. & Borve, E. (2017)	Explore teacher perception of the impact of the physical environment on the culture of play in the classroom	Private kindergarten in Norway consisting of 73 children and 18 lead and assistant teachers	Case study using recorded staff interviews	Teachers arranged the environment with expectations and intentions of learning in mind that often led to gender influenced design.
Chapman, R. (2016)	Explore how gender roles might be displayed or supported without the teacher being aware	2 preschool teachers, 2 assistant teachers, 39 children ages 4-5 years old from Australia	Interviews with teachers and observations of children	Teachers' planning of activities is influenced by how they viewed play and gender roles.
Rodriguez, MdC., Pena, J.V., Fernandez, C.M., & Vinuela, M.P. (2006)	Investigate gender discourse used by nursery school teachers	35 teachers of children aged 3-6 years old in Spain	Semi-structured interviews of 7 focus groups	Teachers reported a gender division in areas of the classroom where children play that is consistent with their expectations that children play in traditional gender defined ways.
Granger, K., Hanish, L., Kornienko, O. & Bradley, R.H. (2017)	Explore the frequency that teachers facilitated gender conforming and gender-neutral activities during free play	37 female teachers in Head Start classrooms	Observation of teacher-student interactions and group composition during free play	Teachers facilitated gender-typed activities based on the gender make-up of the group. Teachers facilitated gender-neutral activities with all girls groups more frequently than with all boys groups.
Logue, M.E., & Harvey, H. (2010)	Understand preschool teacher's views and practices on pretend play	98 teachers of 4-year-old children	Mailed questionnaires	Teachers reported significant differences in play for boys and girls. Teachers intervened in social conflict among boys more often than girls.
Lynch, M. (2015)	Explore how teachers discuss gender in social media	7 Online message boards 7 Kindergarten teachers	Netnography of data collected from social media and semi-structured interviews.	The most prevalent theme, "Dramatic play is for girls." Results of interviews indicated that teachers' views of gendered play are projected onto their students.
Lynch, L. (2016)	Analyze the content of teacher selected children's literature in preschools in Sweden	618 book readings of 433 unique books across 6 preschools in Sweden to children aged 3-6 years	Teachers recorded the books read during group story times over a period of six months	Significantly less girls were main characters than boys. Teachers' and children's choice of books to read was significantly more likely to include a male main character than a female.
Sniegulska, M., & Pisula, W. (2013)	Analyze children's free play with a new toy	189 preschool children aged 3-7 years old from private and public kindergartens in Poland	Video recorded, 15-minute observation of child with a new toy	No gender differences were found in exploration of toys.
Tomes, R. (1995)	Explore teacher influence on children's selection of activities and areas	58 children aged 3-5 years old and their teachers	Observations during free play once a week for 6 weeks.	Students were drawn to areas of art, block, library and science if the teacher was present. Boys preferred large blocks and girls preferred to play in the art area.
Teacher Perceptions				

Bosacki, S., Woods, H., & Coplan, R. (2015)	Explore early childhood teacher's perceptions of rough and tumble play based on the gender of the child	22 teachers of young children in Canada	Online survey collecting demographics and beliefs and attitudes related to hypothetical play scenarios	Physical play is perceived differently by male and female teachers. Male teachers reported that boys who were more physically aggressive in their play would perform better academically and would be less likely to be excluded. Female teachers held the opposite belief.
Dewar, B., Servos, J., Bosacki, S., & Coplan, R. (2013)	Explore early childhood teacher perceptions of how gender impacts the classroom.	41 teachers throughout Canada	Semi-structured telephone interviews	Themes of professional development, critical self-awareness, and critical thinking emerged. Teachers saw reflection as a way to become aware of their own biases and promote more inclusive gender roles.
Duke, T.S. & McCarthy, K.W. (2009)	Literature review of sexuality and sexism in the context of early childhood education	31 articles published between 1975-2007	Coding system based on publication type, research design, and emergent themes	Eight articles described ways that programs in early childhood and elementary school reinforce gender roles and the oppression of women noting children's literature and television programming as a source for stereotypes.
Erden, F. (2004)	Explore early childhood teachers' attitudes toward gender roles and discipline	130 female public school teachers of kindergarten and first grade	Attitudes Toward Gender Roles Scale (AGRS) and Attitudes Toward Discipline Scale (ADS)	Up to 40% of teachers agreed with gender traditional statements and researchers found a statistically significant relationship between teachers' attitudes towards discipline and their attitudes towards gender roles.
Hyland, N. (2010)	Review of research on developing practices that address equity in the classroom	Review of two approaches: *culturally relevant teaching* and *critical pedagogy* to develop equity	Describe research showing how two pedagogies have been use in early childhood classrooms to address race, gender, and sexual orientation	Research identifies ways to reconstruct gender stereotyped messages, which can be detrimental to both boys' and girls' development. Teachers role is to address power imbalances across race and gender through empowering underrepresented children.
Hyvonen, P. (2008)	Explore teachers' perceptions of mixed-gender play activities	14 preschool and primary teachers in Finland	Teacher interviews	Teachers noted a goal of education should be to overcome gender boundaries. Teachers intentionally do not separate gender in their classrooms and they question gendered behavior and ask children to reflect on it.
Lundeberg, M.A. (1997)	Investigate how preservice teachers' perceptions of gender compare with teacher and student interactions	48 preservice teachers	Analyze data on participates in a discussion of gender bias in classrooms	Majority (71%) of preservice teachers thought that classroom discussion was equal. More males contributed comments in class discussion. Preservice teachers reflected on the importance of creating equal experiences for both genders.
Pellegrini et al. (2011)	Explore the differences in observations and ratings of preschool children's aggression	89 preschool children 5 five teachers	Daily observations of children Teacher checklist to measure child aggression	Trained female researchers rated children's aggression the same as female teachers who had not been trained. Trained male researchers recorded more aggression compared to females.
Sandberg, A., & Pramling-Samuelsson, I. (2005)	Investigate the different ways male and female preschool	20 preschool teachers in private and public	In-person, semi-structured interviews	Preschool teachers reflected their play as children was gender stereotyped. Female teachers had no play

	teachers think of play	preschools in Sweden		willingness and avoided playing with children as they thought they would disturb the play. Male teachers were more playful.
Trawick-Smith, T., Wolff, J., Koschel, M., & Vallarelli, J. (2015)	Examine the effects of toys on play, including factors that enhance learning and development	Four classrooms of 60 children aged 3-4 years old. Parents and teachers nominated 9 toys for the research project.	Observations of toy use recorded using hidden cameras and microphones. Toy quality was assessed using a play quality with toys (PQT) measure	Most of the toys received the highest quality scores when boys were engaged with them, suggesting that parents and teachers need to identify toys that can engage boys and girls in equally beneficial ways.
Teacher Interactions				
Adriany, V. & Warin, J. (2014)	Explore the relationship between care and gender in an early childhood environment	4 teachers, 1 principal, the school owner, and 28 children between 2 and 6 years old in Indonesia	Ethnographic research using field notes, interviews with adults, child conversation, and artifacts	Teachers care for children in stereotypical ways that likely perpetuate gendered behavior in children. While most differences were celebrated at the school, gender was not outwardly addressed.
Benozio, A. & Diesendruck, G. (2017)	Assess how children are influenced by an authority figure in behaving toward others	111 children aged 3-6 years from 5 kindergartens in Israel	Teachers randomly assigned to demonstrate a preference and child behavior assessed on their response related to teacher's preference	Children age three to four years old distribute items based on being fair or equal, regardless of teacher's preference. Children aged five to six, distributed items based on teacher preference and matched gender of recipients. Teacher interactions may impact how children respond.
Bigler, R. S. (1995)	Explore how the use of gender categorization in the classroom attributes to gender stereotyping	66 children ages 6-11 in three classrooms	Classroom teachers randomly assigned to exhibit three categorization styes: gender, color group, and control group.	Children in a classroom where the teacher used gender as a categorization method increased their gender stereotyping. Children in these classrooms were more likely to categorize occupations as appropriate for male or females along traditional gender stereotypes.
Hedlin, M. & Aberg, M. (2018)	Researchers investigate the conditions of stereotypes in teacher training and their influence on children in the classroom	10 female and 10 male preschool teachers in Sweden 7 teachers working with preservice teachers	Semi-structured interviews lasting 30-60 minutes. Ethnographic observations and interviews with preservice teachers.	Researchers identify that teachers and staff found girls demonstrating headstrong and disobedient behavior as less permissible than boys demonstrating similar behaviors. Girls acting this way were dismissed and perceived as "very troublesome."
Martin, K. (1998)	Investigate the development of the gendered child in preschool	5 preschool classrooms serving 5-year-old children	Qualitative semi-structured observations and field notes of classrooms	Four teaching practices (behavior management, voice control, verbal and physical directions of body, and physical interactions between children) and one parenting practice (clothing selection) created gendered differences.
Olsen, B. & Smeplass, E. (2016)	Researchers report and reflect on	671 teachers and staff	Questionnaire of 13	Teachers' response to dilemmas were nearly identical,

	gendered attitudes of kindergarten staff members	members at 80 Kindergartens from 2 Danish municipalities	pedagogical dilemmas, 2 specific to gender	regardless of the teacher's own gender. Staff, regardless of gender, treated boys and girls differently.
Owens, S., Smothers, B.C., & Love, F.E. (2003)	Examine gender bias in schools related to access of education and gender inequalities	Systematic review of literature	Three areas of focus: history of women and education, schools encouragement of gender inequality, and solutions for equity in schools	Gender bias or sexism in the classroom is subtle and often unconscious. Differences in how boys and girls are treated results in a learned pattern of how to behave early on in life.
Şahin-Sak, İ. T., Sak, R., & Tezel-Şahin, F. (2018)	Investigate the perceptions of preschool teachers related to behavior management	310 preschool teachers in Turkey	Questionnaire	Female preschool teachers were more likely to use techniques for behavior management involving listening, relationship building, and comforting children.
Vitiello, V.E., Booren, L.M., Downer, J.T., & Williford, A.P. (2012)	Investigate the source of variability in child engagement between child factors and classroom settings	342 preschool aged children (34 – 63 months) from 100 classrooms in 40 urban schools 84 female teachers	Classroom observation of activity settings and inCLASS observational system	Child gender was not significantly associated with children's negative or positive engagement with their teachers.
Social Standing				
Al-Thani, T., & Semmar, Y. (2017)	Assess prosocial behaviors of preschool children and differences in teacher perceptions of gender	472 children and 22 teachers from 10 schools in Doha, Qatar	Teachers completed the Prosocial Behaviors of Children-Teachers' Perceptions instrument	Teachers perceived that boys displayed less prosocial behaviors than their female peers. Significant differences in gender occurred in teacher preferred behavior, peer preferred behavior, and school adjustment.
Sullivan, J., Moss-Racusin, C., Lopez, M., & Williams, K. (2018)	Explore the impact of gender stereotyping on young children	Study 1: 635 adults Study 2: 697 adults All recruited from Amazon Mechanical Turk.	Study 1: Online task to rate typical or desirable characteristics for 3 year old by gender Study 2: Online task of gender conforming and non-conforming vignettes of preschool applications	Study 1: Researchers developed a list of traits for each gender. Study 2: Stereotype conforming boys and girls were more likeable than their non-conforming peers. Girls overall were more likeable than boys.
Gender Identity				
Burdelski, M. & Mitsuhashi, K. (2010)	Explore how teachers and children use the word *kawaii* (cute, loveable) and how it impacts social interactions in the classroom	Private day care classroom with 14 children and their female teachers in Japan	Recorded observations of the classroom taken 1-2 times a month over one year	Children learn the meaning of *kawaii* through social interactions. Teachers use *kawaii* as an indication of gender. Teachers assessed girls using the term. Female children used *kawaii* more when referring to themselves and female peers.

Conclusion and Discussion

Several notable ideas emerged from this review of early childhood literature related to gender. First, teachers' perceptions of gender are influenced by their own gender and prior experiences (Borve & Borve, 2017; Bosacki et al., 2015; Pellegrini et al., 2011; Sandberg & Pramling-Samuelsson, 2005). Second, to some degree interactions in the classroom contain bias and stereotypes and implicit gender bias may be present in how activities are designed and what materials are selected for use in the classroom (Borve & Borve, 2017; Rodriguez et al., 2006; Trawick-Smith et al., 2015). Third, children receive gendered messages from early childhood teachers which may impact their own view of themselves (Adriany & Warin, 2014; Burelski & Mitsuhashi, 2010; Granger et al., 2017; Olsen & Smeplass, 2016). Next, these ideas are interpreted while considering implications for science teaching and learning in the early years.

When applying a lens of science learning to findings in the *Curriculum* category, it is important to remember that an intense early interest in science for girls is related to a higher self-concept in science later in childhood (Leibham et al., 2013). Young girls may self-select play that is more nurturing in nature but the teacher's planning could also be contributing to traditional gender play in the classroom. Early childhood teachers are influential in fostering science interest through their presence and planning of activities that increase opportunities for science play for children (Leibham et al., 2013; Tomes, 1995). Research shows that early childhood teachers do not feel confident teaching science and that they would prefer to play with children in other areas of the classroom instead (Gerde et al., 2018; Kallary & Psillos, 2001). As a consequence, the science area of the classroom may not be selected for play as often and science content may be addressed less frequently than other content areas which could be especially detrimental to igniting and fostering young girls' early interests in science. Further, not all early childhood programs are equally focused on science. Nature-based preschool programs have a special focus on environmental education and spend large amounts of time in the outdoors. Such programs may provide more frequent opportunities for science learning yet little is known about the role of gender in such experiences. It is possible that nature provides an optimal backdrop for equal science learning for both genders. Children enrolled at nature preschools may accrue less gender bias and gendered beliefs about themselves and their science abilities when immersed in a natural outdoor learning environment as compared to a traditional early childhood setting that contains gendered play areas and gendered toys. More research on environment and curriculum is needed to answer these questions.

In early childhood education, research shows that interactions between children and teachers have an important role in predicting child outcomes (Early et al., 2007). The results from this review indicate that teachers interact differently with children based on their gender (Granger et al., 2017; Olsen & Smeplass, 2016). The impact of differential treatment on science learning is still largely unknown and represents a gap in the literature for future researchers to investigate. Interactions during science activities and exploration in the early childhood classroom could be a key element to understanding later differences in science achievement and interest between boys and girls. And although the focus of the review is constrained to perceptions of early childhood teachers, it is worth noting how interactions with other authority figures, such as parents, could be contributing to the divide. In a study of interactions between parents and their children at a science museum, parents used more explanatory conversations with their sons than with their daughters (Crowley et al., 2001). In fact, conversations with sons were three times more likely to include explanations and this held true at all ages (1-8 years) even though children who heard explanations had rarely asked questions (Crowley et al., 2001). It is not a far leap to suggest that similar differences in interactions could be happening in early childhood classrooms given the research presented in the *Teacher Interactions* category showing that child gender impacts teacher's responses and teaching practices (Adriany & Warin, 2014; Martin, 1998; Olsen & Smeplass, 2016). Fortunately, a recent study found that of 755 questions asked during preschool science lessons, no significant differences were found regarding gender of the child recipient (Hamel et al., 2021). Further, Granger and colleagues (2017) found that gender-neutral activities were implemented more frequently with groups of girls than boys. While it is promising that teachers are engaging with young girls in gender-neutral activities, it stops short of crossing into more stereotypically masculine activities, which are often associated with science. Providing stereotypically masculine activities to all genders is an opportunity to counter stereotypical gender activities by providing a variety of experiences to all children regardless of gender.

Findings from the social standing category are relevant to the topic of gender and science because girls (and boys, for that matter) may be more inclined to conform to gender stereotypes to achieve approval or be liked. Masculinity is often linked to traits of objectivity, lack of emotion, and rationality, which frequently are associated with the subject of science (Brotman & Moore, 2008). Exhibiting feminine nurturing behaviors such as building relationships, creativity, and showing emotion can be viewed as incompatible to science (Brotman & Moore, 2008). Unfortunately, these associations may lead children to conform for the sake of acceptance or contradict gender stereotypes with the risk of being rejected. Of course, it is important to note that real differences may exist in social behaviors of boys and girls. Some researchers have found that relational aggression is more common in girls in early childhood and boys show more physical aggression than girls, although not significantly (Ostrov et al., 2004). While difference between social behaviors may exist, teachers should encourage all students to engage in science activities and content. Attempts have been made to contradict associations of masculinity and science including a program coined "Creative Expression in Science" (Meyer, 1998) aimed at elementary science teachers. Early childhood teachers could also benefit from professional development and training that emphasizes acceptance and encouragement of all students to engage in science topics.

Lastly, language is powerful and has the ability to influence how children view themselves. The use of the Japanese word *kawaii* is an example of explicit labeling that impacts how children identify themselves by gender (Burdelski & Mitsuhashi, 2010). Explicit labeling is an important facet of DIT which provides an explanation of core processes responsible for contributing to young children's understandings of bias and stereotype, including gender. DIT posits that four factors may influence the formation of gender bias or stereotypes in young children, one of which is explicit labeling and use (Bigler & Liben, 2006). If children, especially young girls, are forming (mis)understandings of themselves and their science abilities during preschool, it is important to understand not only where and from whom these messages originate (parents, teachers, and society), but how children receive and internalize them as part of their identity.

These findings also have implications for early childhood teacher preparation programs who can apply and share the results within required coursework on gender equity and science pedagogy. Early childhood teachers' awareness and understandings of their own biases and perceptions can help them to reflect on their pedagogical choices and the subsequent impact on children's learning opportunities in the classroom. Policymakers and administrators should also consider offering professional development for early childhood teachers on promoting gender equity by eliminating gender bias and stereotypes as a way to enhance teacher practices. It should be emphasized here that this review included research conducted in international settings which requires special consideration of socio-cultural influences of gender development. Therefore, the cultural norms and context of each unique early care program should be thoughtfully considered.

Limitations

This review explored how teacher perceptions related to gender influenced teachers' practices. Limitations of the review include the small number of articles collected. Although efforts were made to encompass all relevant articles in the early childhood literature, it is possible that some studies were missed. A wider search to include other areas of male-dominated domains and careers, such as math, might also provide additional insights but was beyond the scope of this review. In addition, the body of literature analyzed relied heavily on self-report measures such as questionnaires, surveys, and semi-structured interviews of teachers to identify their perceptions and gender bias. For these types of measures, social desirability may play a role in how teachers reported their perceptions of gender and lead to answers that were not true depictions of actual perceptions. One form of bias termed *implicit bias*, is based on the notion that unconscious beliefs or processes can impact our actions. For teachers, this is particularly important because implicit biases may affect teachers' "understanding, actions, and decisions in an unconscious manner" (Staats, 2016). A well-intentioned teacher may unconsciously interpret a situation or behavior in a way that is biased therefore observations of children and teachers during science activities may provide a different perspective.

Future Directions

The results of this review highlight future avenues for research. First, it would be useful to use measures that can reveal implicit gender bias. The desire to respond in a more socially acceptable manner may play a role in how teachers report their perceptions and feelings about gender. A second direction for future research would be an increase in observational data collection to observe teacher and child behavior in natural classroom settings. Only one-third (34%) of the articles in the review included classroom observations, with others focusing instead on surveys and interviews. Additionally, preschool aged children are capable of answering questions related to their perceptions, interests, and experiences and could provide insight into preschool science activities.

Looking forward, it is also important to recognize that separately, the fields of science and early childhood education have made valuable contributions to understanding this topic. Gender gaps in science fields and occupations are widely acknowledged and continue to be investigated. At the same time, early childhood researchers are dedicated to understanding the teaching and learning of science in early childhood (Silby & Watts, 2017). However, exploring science teaching and learning in early childhood specifically for gender bias or differential treatment by gender is lacking. Expanding the field to include more investigations at the early childhood level could provide a more complete understanding of the issue of gender inequality in science fields prior to formal schooling. It also has the potential to provide valuable information about the teacher's role in counteracting or contributing to gender differences in science with an overarching goal of increasing the participation of women in the science field. Further investigation into this topic may prove mutually beneficial for both the fields of science and early childhood education. An area of importance for further research is examining how gender bias in the classroom impacts all children, including gender-nonconforming children. Early childhood classrooms should provide equitable science learning opportunities for all children.

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Research Article

Preschoolers' use and exploration of concepts related to scientific phenomena in preschool

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Abstract: The study described in this paper concerns science education in preschool, more specifically how young children in preschool settings invent, develop and explore science and scientific concepts in problem-solving and communicative situations. The aim of the paper is to discuss young children´s concept creation and draw conclusions for early science education. The method used was a secondary analysis of empirical material drawn from three previous studies carried out by the authors. Examples of preschool children's use of language were extracted and was, for the purpose of this study, analyzed with a new focus on children's use of concepts. The re-analysis draws from Vygotsky's theoretical framework on children's conceptual development and appropriation of new concepts (Vygotsky, 1934/1999; Åkerblom, 2011) and from the later Wittgenstein (1986) on the role of language meaning in understanding. The findings underline the importance of allowing preschool children to invent, develop and explore science and technology concepts, as well as implications for preschool teachers to create dialogic spaces for the children to do so. The limitations of the study are however that it is based on a limited number of examples and even though it can give implications and point out directions, is not conclusive and should be followed by further research.

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Introduction

An important reoccurring issue in ECEC concerns how to make it possible for young children to make sense of basic science. In particular, one domanin emphasized in the curriculum involves supporting and developing children's understanding of concepts in natural sciences (eg. Fleer, 2009; Gomes & Fleer, 2018; Siry & Kremer, 2011). Policy-documents in science education internationally emphasize that there is a large value in teaching science to children already in preschool (Siry & Gorges, 2020). In the Swedish curriculum for preschool (Curriculum for the preschool [Lpfö 18], 2018) and the educational programme for preschool class (Curriculum for the compulsory school, preschool class and school-age educare [Lgr 11], 2018) there are goals that aim to contribute to children's abilities to express scientific knowledge in different ways. Furthermore, the children in preschool class and preschool should be supported to develop abilities to discuss, ask questions about and explore scientific phenomena and technology processes. However teaching children about scientific knowledge, actualizes a dilemma, since scientific explanations and procedures both have to be presented in a form that makes experiential sense to preschoolers but is at the same time true to scientific knowledge (Åkerblom et al., 2019). Another important issue is the role that science concepts play, both as they are invented by children themselves in their attempts to make sense of the world around them; in addition to the way in which preschool teachers teach about scientific concepts. It is, however not clearly stated in the goals if, how, or for what purpose the preschool teachers should teach scientific concepts to the children.

The research literature on early science and technology point to the value of providing young children with opportunities to engage in science and technology (eg. Fleer, 2009; Fleer & Pramling, 2015;

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Mawson 2010; Milne & Edwards 2011; Robbins 2005; Rogers & Russo 2003;Siry, 2013;). In a longitudinal study that explored early science experiences in preschool, Saçkes et al. (2011) suggested that availability of science materials and time to explore those facilitated children's participation in science activities. However, the results of the longitudinal study also indicated that those early science experiences were not predictive for the children's later science achievements in school (ibid.). The results could be interpreted that access to learning materials and time for exploration are not the only factors that matter for children's science understanding. In a Swedish study about what shapes science activities in preschool by Sundberg et al. (2018), two factors were found to be of particular importance; the structure and educational culture of the preschool practice. When the preschool community was characterized with joint understandings of the purpose of the science activities this allowed the preschool teachers to frame the science content and support the children's science learning in child-responsive science activities. Furthermore, Fleer (2009) argues for the importance of an adult mediating science concepts to children to pay attention to in preschool settings. To be able to distinguish the scientific concepts and make scientific sense of science materials, the teacher must support the children's concept creation. Preschool children's opportunities to make scientific sense of preschool activities are closely related to the teacher's perspective on science and how they view the children's capacities for learning (Saçkes, 2014). Gomes and Fleer (2018) showed that if the teacher had a 'sciencing attitude' and could see how the affordances of the environment could enable science learning for the children.

The significance of considering the diverse ways that children express and make sense of scientific experience has been stressed by a number of researchers (eg. Åkerblom, 2015; Siry & Gorges, 2020; Siry & Kremer, 2011). One example was provided by Siry and Gorges (2020) who conclude, based on a study of a multilingual child, that children need to use multiple resources to express what they understand. The girl in their examination used multiple modalities, bodily language to enact her science understanding. Furthermore, dialogues with children can provide opportunity to shed light on how children conceptualize science and technology phenomena (Rogers & Russo, 2003). Everyday conversations with children about their understanding are critical to explore how they interpret their experiences according to Siry and Kremer (2011). The authors further highlight that children should be given opportunities to share their understandings through discussions in relation to science activities (ibid.). Saçkes (2014) concludes, based on a study on children's understanding of the day and night cycle, that science teaching in preschool should be inquiry-based and playful, with hands-on activities that allow the children to be active participants in the learning environment. Pramling and Pramling Samuelsson (2011) emphasize the role of language and linguistic mediation of a child's experiences by a more competent partner, and the use of children´s different understanding as a resource and as a pedagogical principle.

While the role of preschool teachers for children's learning scientific concepts are emphasized in research, there are at the same time a number of studies showing that preschool teachers have difficulties supporting young childrens conceptual development (e.g. Gomes & Fleer, 2018, Saçkes et al., 2011; Siry & Kremer, 2011; Tu, 2006). This may have to do with the preschool teachers lacking formal science and technology knowledge (Saçkes et al., 2011), and that preschool does not have a tradition of teaching science and technology. The gaps of knowledge acombined with the lack of tradition to teach science may create a sense of insecurity. This insecurity may also have to do with a lack of knowledge about how young children invent, develop and use science concepts in everyday preschool activitites. To illuminate these issues this study aims to contribute to the discussion of how young children use concepts through a re-analysis of empirical material of children using science/technology concepts in communicative situations in preschool settings.

The aim of the paper is to discuss young children´s concept creation during exploring activities and reflection over their own language use, and to draw conclusions for early science education. The significance of this study thus lays in the potential to provide preschool teachers with insights about children's concept creation.

Questions:

1. How do preschool children themselves invent basic sientific concepts?
2. How do preschool children develop basic sientific concepts?
3. How do preschool children explore basic sientific concepts?
4. How can children´s concept development and scientific sense-making be supported in earlychildhood settings?

Early Science in Swedish Preschool and Preschool Class

Most Swedish children between 1-5 years attend early childhood education, or *preschool* as it is generally called. Swedish preschool is regulated in the National Preschool Curriculum (Lpfö 18, 2018) and the municipality is required to provide pre-schooling for all children residing in Sweden from the age of one. Preschool is voluntary but as the children turn 6 they go on to obligatory *preschool class* for one year, before entering compulsory school. The educational programme for preschool classes stipulates that it should '…contribute to the continuity and progression of the pupils' development and learning as well as prepare the pupils for continued education' (Lgr 11, 2018, p.19).

The educational programme for preschool class should provide education that is play-based and emanates from the child's interests. Children should be given opportunities to develop understanding of the surrounding world as well as making sense of scientific concepts (Lpfö 18, 2018). Furthermore, the curriculum states that it is the preschool teacher who is responsible to support children's attempts of making sense.

When it comes to contents such as science and technology, there are specific goals in both curricula. The goals of the preschool curriculum concern the ability to *express* scientific/technological knowledge in different ways. It also stipulates that children should develop their ability to discuss and ask questions about these issues. In the educational programme for the preschool class, it says that teaching should: '…contribute to the development of the pupils' interest in and knowledge of nature, technology and society, by giving them the opportunity to explore and pose questions on and discuss phenomena and relationships in the world at large.' (Lgr11, 2018, p.20). However, to be able to explore, discuss and understand science, children in preschool and preschool class need to be provided with conceptual knowledge. However, it is not clearly stated in the goals what scientific concepts preschool teachers should teach. Altogether the combination of ambitious science teaching objectives with unclear guidelines of how to organize activities and spaces for these activities constitute large challenges for preschool teachers (Nordén & Avery 2020).

Previous Research on Children Making Sense of Science and Technology – An Exploratory Literature Review

The purpose of the exploratory literature review was to find research with relevance for preschool science education and particularly on the role of children's scientific and technological concept development in preschool contexts.

Piaget (eg. 1971, 1973) was probably one of the first scholars to show that young children had their own, often rich and creative conceptions of the world around them. Piaget (1973) also saw, through numerous interview studies where children were invited to reason about different natural phenomena, that their intuitive conceptions about different aspects of the world would often be diverse from the 'scientifically accepted' way of thinking (Saçkes, 2015b). Piaget (1969; 1971; 1973) was mainly interested in finding aspects that were stable and general in children's thinking. Since then, a lot of studies have been carried out to explore children's intuitive conceptions and the way they may differ from scientifically accepted ideas (e.g. Driver & Easley, 1978; Osborne & Freyberg, 1985; for an overview see Duit, 2009). The results of these early studies have been known as *Children's Science* (Fleer & Pramling, 2015), and for almost 30 years those studies shaped how science education was viewed and implemented (Saçkes, 2015a). In some of these studies children's intuitive ideas and thinking was considered as something to overcome and as obstacles to learning the 'right scientific ideas'. However other studies have been seeking answers to why the challenges to learning and teaching science to preschool children occur (Sundberg et al., 2018; Andersson et al., 2020) and obstacles to conceptualization of abstract science concepts (Güneş & Şahin, 2020; Hobson et al., 2010; Saçkes et al., 2011; Saçkes, 2014).

The idea of children having to overcome the obstacles of alternative conceptions is in contrast to more recent research, where children's rich conceptualization is emphasized and considered important to listen to and value (e.g. Robbins, 2005; Siry, 2011; Siry & Gorges, 2020). Siry (2011), suggests with reference to Joe Kincheloe, that science teaching in ECE should start with the assumption that even young children can produce new and creative knowledge about scientific phenomena. Consequently, the way children and their knowledge about science and technology are viewed, have large impact on how early education is organized for and related with them. When Piaget's studies were critically examined, this have opened up for a discussion about how the child was viewed in experiments and interviews (e.g. Donaldson, 1978; Hundeide, 1977; Pramling, 2006). Güneş and Şahin (2020) found in a study of five-year olds' epistemic thinking about the concept of time, using children's drawings, that in contrary to Piaget's (1969) interpretations, five-year olds could demonstrate abstract thinking in conceptualization of time. This research points at the importance of considering aspects such as the situation and discursive factors as well. Siry (2011) further claims that when children's science is studied when they interact and a with a research focus on their embodied enactment, rather than just verbal speech this can support a new view on children and their investigations as rich of resources instead of as lacking something. Furthermore, to express their understandings, young children often include a broad repertoire of multimodal and other signs so make their ideas visible (Siry & Gorges, 2020). As an example, Kalogiannakis et al. (2018) showed in a study of preschool children's understanding of magnetism that drawing allowed the children to express their understanding of the phenomenon, and thus give their teachers an opportunity to get insight into children's thinking about magnetism. In dialogues with children around their investigations and explanations it is possible to uncover how they learn and think (Fleer & Pramling, 2015) and when asked to reflect over the meanings of words they used in their explanations, this could provide opportunities for the children to become aware of their thinking and use of language (Åkerblom, 2011), and metaconceptual awareness, also stressed by Saçkes (2014).

Andersson and Gullberg (2014) showed that conceptions about children and their thinking abilities also have impact on how their activities and speech are interpreted. A teaching episode in preschool, with the aim of developing children's conceptual understanding about floating/sinking, was analyzed from two different analytical perspectives. When the activity was analyzed with a focus on whether the children developed their scientific thinking, the result did not indicate that they had appropriated scientific concepts or that their scientific thinking had developed. However, when the activity was viewed from a different perspective, with a focus on children's feelings as participants of a science activity, the result showed in contrast, that the activity of speaking and thinking about density had been a positive experience. So, the two analyses of the same preschool activity showed a difference in how science was constituted that was related to how the children were viewed (Andersson and Gullberg 2014). A pedagogic conclusion to draw from this research is that if children are perceived as resourceful, teaching must be based on children's experience and their conceptions as resources when developing children's thinking further.

Another way to handle the relation between children's experience and scientific concepts is to organize drama-activities and role-play to support children's abstract thinking and make science meaningful to them. According to Ødegaard (2003), the use of drama can be a way to support children's meaning making of science concepts for which they lack words, or for abstract explanations of phenomena imperceptible to the senses. In a study carried out by Åkerblom and Pramling (2019, 2020) dramatizing was discussed as a form of teaching chemistry concepts and processes to young children, responsive to how they make sense. Six-year old children (n=11) from a preschool class were interviewed after they had participated in a workshop where they were invited to dramatize certain chemistry concepts and processes. Dramatizing was in the study understood as role play in an imaginary dimension (as if). Åkerblom and

Pramling (2019) argue that central to dramatizing is how participants distinguish, relate and shift between engaging with the phenomena and the processes of 'as if' and 'as is'. Also, the way that the children spoke about their participating in the activity indicate that they have viewed themselves as agents, rather than being recipients of information.

Based on the results of a study of one pluri-lingual child´s meaning making in a science activity, Siry and Gorges (2020) argue for the value of considering the richness and diversity of resources children use to make sense of science. This is especially important in multilingual preschool settings, since using non-verbal resources can facilitate communication, not only between the children, but also for teachers to gain deeper insights in meaning- making processes of children. This research underscores the claim that science education for young children should aim to create dialogic spaces where children and their teachers can negotiate and develop meanings about science phenomena and use a variety of resources to do so.

Theoretical Framework

The notion of *language* has different meanings in different contexts, and how language or the activity of languaging is viewed, have great impact on how teaching languages is organized and structured. How language is understood also influences the views on scientific concepts and how those are to be mastered by children. The language philosopher Wittgenstein (1953/1968) distinguished in his writings two very different ways of viewing the function of language; one view was language as a structural, focusing language as a system of meanings and the other view was language as expressive, focusing the activity of expression.

With a structural view, the main function of language is to name and describe objects and aspects in the world. Every word can be perceived as containing its meaning- the object for which the word stands. The process of learning to understand a concept means to establish the correct relationships between objects and words. The structural conception of language is in many ways in line with the common sense understanding of what language is and how language works and can also, to some extent be identified in the cognitive research tradition (e.g. Vosniadou, 1994) and in the work of Chomsky (Golumbia, 2014). From a structural perspective on language, to learn scientific concepts, the main problem to address lays in the meaning those concepts are given and the presence of alternative meanings and competing systems of meanings. From a cognitive perspective the unit of analysis is the individual and consequently the purpose of teaching is to make the child change from alternative frameworks to scientific concepts (Åkerblom, 2011).

With an expressive view, language is understood as activity of expressing something, and language meaning is seen as constituted in its use rather than something stable that exists beforehand. Language, from this perspective is seen as something open and mobile (Åkerblom, 2011). To emphasise the activity of using language, the notion of 'languaging' is often used. The notion of languaging refers to communication and includes the processes of making sense of, and shaping experience through language (Lewis et al., 2012). According to (Wittgenstein, 1953/1968), with an expressive conception of language, it is learnt during the engagement in and living in the world. Language is created and it arises in practice and could be described as both subjective (as in understanding) and intersubjective (as in communication).

When Vygotsky (1934/1999) studied the connections between language and thinking and how they were established in the child's development, *word meaning* was his unit of analysis. Word meaning, according to Vygotsky is at the same time both language and thinking. Appropriation of word-meaning is a complex process and starts as the child understands that there is a relation between things and words. According to Vygotsky (1934/1987) a major result of his numerous studies was the result that word-meanings are something highly dynamic and changing.

> Word meanings are dynamic rather than static formations. They change as the child develops; they change also with the various ways in which thought functions. (Vygotsky, 1934/1987, p. 217)

Vygotsky (1934/1987) saw the relation between two aspects, such as language and thinking, as in itself an activity and spoke of the activity of thinking as *generalisation* of concepts. According to Vygotsky conceptual development implicates phases of different generalisation. This is similar to Vygotsky's

(1930/1995) work on imagination and creativity as the ability to combine and interpret different impressions, a mode of thinking. In Vygotsky's work the dynamic relation between two aspects were always in the fore and he used different notions to describe the aspects. His notions were sometimes overlapping and sometimes through his work used somewhat differently. Those notions have consequently been interpreted and translated in different ways (eg. Veresov, 2004). For the purpose of the present article, some of Vygotsky's concepts will be presented and used for the analysis of children´s reasoning

One such distinction that Vygotsky (1935/1998) made in his work on children's concept formation, was the distinction between what he refers to as *pseudo concept* and *concept proper*. Pseudo concept implies that the child can give a number of examples of the same thing, but without necessarily being able to verbalize what these examples have in common. Concept proper, on the other hand refers to when the child is able to discern, and also express what the examples have in common so that they can be summarized under a label based on their characteristics. Another distinction made by Vygotsky (1934/1987) was between *spontaneous* and *reflected concepts.* A spontaneous concept is something drawn from children´s bodily experiences with aspects of the world, and it is not reflected over. Normally in those cases, the children are not conscious of how they think, whereas reflected concepts are something the children can speak about and see as 'something'. When a concept is reflected over it gives the child opportunity to understand that this 'something' can be conceptualized in many different ways, something that opens up for learning to see differently.

Vygotsky (1934/1999) distinguishes *everyday concepts* from *scientific concepts,* and he viewed the relation between those two as particularly fruitful in relation to science education. Everyday concepts relate to children´s empirical experience and the consequences that can be drawn from experience. In contrast scientific concepts are concepts with specific and socially agreed upon meanings, connected to a certain field. Vygotsky (1934/1987) also explored the relation between the *sense* of a word and its *meaning* and made a distinction between them. The *meaning* of a concept is according to Vygotsky closely related to what we would call the agreed on definition of a word. The *sense* of a word, however, can be described as the personal, creative aspect of it. It is something that 'enriches' or creates a deeper meaning, and it is depending on the context of use. Meaning and sense could further be connected to what Vygotsky spoke of as scientific and spontaneous concepts (Vygotsky, 1934/1987). A scientific concept would thus be associated with the notion of meaning and everyday concept with the notion of sense.

Vygotsky (1934/1999) emphasized the relation between everyday and scientific concepts as necessary for children's learning. Scientific concepts are those that in a meaningful way for the children can be related, but not reduced to the children's everyday experience and concepts. Vygotsky argues, much like Wittgenstein (1968) that learning to use language (for example scientific concepts) implies to play with its function, and to reflect on its meanings within an activity. New concepts must also be developed and created in activity as the child actively reflects over it while using the concept. When children's experiences meet scientific terms with specific, agreed upon and established meanings, children learn new ways to conceptualize the world and aspects of it (Vygotsky, 1934/1987). But this does not happen without some tension, since children then have to leave their spontaneous and intuitive ideas. The encounter between the child's own experience and new and scientific concepts requires active and creative elaboration of those concepts (Åkerblom, 2011).

Method

The present study consists of a secondary analysis (Sherif, 2018) of empirical material retrieved from three previous studies carried out by the authors. This particular method was selected since it was appropriate for the research objective of the present study. Since the data was originally created for different purpose, a secondary analysis was performed based on a new theoretical framework with the aim to inform new research questions (Smith, 2008). The original data consisted both of video-recordings of technology activities (Thorshag, 2019) and from dialogues with six-year-old children about physical phenomena and chemical concepts (Åkerblom, 2015; Åkerblom et al., 2019). From the empirical material, a number of examples of preschool children's use of language and conception creation were extracted. For the purpose of this study, those examples were re-analyzed with a new focus on children's use of concepts. Theoretically the re-analysis draws from Vygotsky's theoretical framework on children's conceptual development and appropriation of new concepts (Åkerblom, 2011; Vygotsky, 1934/1999) and from Wittgenstein (1953/1968) on the role of language meaning in understanding. The original studies will be shortly described below.

Technology Study

The overall aim was to study how children work and explore technology in building- and construction play in preschool (Thorshag, 2019). The activities were both planned by teachers and initiated by the children. To conduct the study and to be able to document the verbal language as well as the body language, video observations were chosen as the main tool. Field notes were taken at the observations to document gatherings before and after the activities, and to give background and context to the activities. In all 11 preschool teachers and 49 children, in the age of 4-5, participated in the study. Every preschool was visited at three occasions. The video recordings were transcribed both regarding speech and action (Heikkilä & Sahlström, 2003)

Children Making Sense of Physical Motion and Basic Astronomy

The overall purpose of the original study was to explore, analyse and describe how children between six and 14 years old (n 64) use language to express and make sense of physical phenomena (Åkerblom, 2011). The empirical examples for the present study were drawn from dialogues with six-year-old (n 18), who all attended preschool class at the time. The children were asked questions intended to point out a problem that could be explained in classical mechanics and basic astronomy: 'What happens when a ball is thrown slantingly up in the air?' 'Why does not the moon fall down?' A dialogue structure was used to encourage the children to reflect on their use of language when explaining the process.

Chemistry Study

The study was an empirical investigation of how concept young children form chemistry concepts. 22 6-year old children from one preschool class participated in a chemistry activity that was playfully enacted at a culture centre for children (Åkerblom et al., 2019). Pre-and post-interviews were carried out with the children and the activity was digitally recorded. Still pictures showing the chemistry activity and the children participating in it was made from the recording and were then used in the post-interviews to create mutual ground for talking with the children about what they remembered from the activity. They were also asked about how they understood the activity that they had participated in and what they thought the activity had intended to illustrate. The empirical material, consisting of the pre-and post-interviews was analyzed with a focus on how the children made sense of basic chemistry processes and concepts like *water*, *molecule* and *chemistry* (as such).

Ethical Considerations

The ethical aspects related to the original studies were handled according to current ethical principles for research (codex.vr.se). This meant that the care-takers of the children that participated in the studies had given their written consents prior to the video-recordings and interviews. The participating children were informed about the studies, that they could choose whether to participate or not, that they could interrupt their participation at any time. The researchers (who both have a background as educators for young children) were also mindful of children's body language and whether it implied that they were not comfortable being interviewed or filmed. In accordance with the ethical guidelines for research by the Swedish Research Council, every child was promised confidentiality, which meant that the names used in the excerpts are fictive.

Secondary Analysis

The analysis was carried out by the two researchers in collaboration. Each researcher selected a number of extracts from their previously transcribed empirical material, consisting of video transcriptions, field-notes and transcribed dialogues. The selection of excerpts to re-analyse, was done collaboratively, with the specific aim to find as rich as possible insight into the participating children's use of concepts. All the selected extracts had in common that they showed different cases of children using concepts to solve problems, explore phenomena, describe processes etc. From the first selection, seven extracts were picked out to serve as an example of a certain way of using concepts. Those examples were thematized and analyzed with a focus on children's use of concepts.

Results

In this section, the results from the re-analysis will be presented closely to excerpts from the empirical data. The findings are structured as examples of children's use of concepts and as situated in a communicative practice. Each theme is presented through one or more excerpts from the data.

Invention of New Technology Concepts in Building and Construction Activities

Example 1. The extract below from a video recording from a preschool show how four children and a preschool teacher play at the building space:

Four children and the preschool teacher Janne (J) are playing in the building space. Janne and Agnes (A) (5:6) start to construct towers with Kapla[1] rods. Agnes wants to build a high tower and Janne proposes a competition about who can build the highest tower. The researcher (R) is also participating while documenting the activity.

> J: (to Agnes) Think about trying to make it *straight*. Look at it, how does it look?
> A: It is a little bit *slanting*.
> J: It is a little bit slanting, yes… which one is the highest?
> A: Mine is the highest.
> /…/
> J: Agnes, how will this end, do you think?
> A: Yes.. (laughter) yes… The one who has the most, I have a whole lot of kapla-rods!
> /…/
> R: How should you do to make it high, the tower then? Agnes, how do you think you should build to hold together and become that high?
> A: You need to be concentrated and then you must be calm.
> /…/
> J:If you now look at your tower and then you look at mine too, how does your look do you think, how does it look?
> A: A bit slanting…
> J: Yes, what should you think about when you build? That you should build…
> A: (interrupts) …straight!

In the extract Agnes uses established and shared concepts like *straight* and *slanting* when she explains to Janne. When she looks at her first tower she can see that it is in danger to collapse and she says: 'My tower can be even higher. It can get more *slanting-high*!' This is her own concept *slanting-high* (*snedhög*t Sw.) to talk about a relationship, ie when the tower is tilted; it falls more easily when it gets high. Her use of the concept indicates that she is aware that to construct a stable tower, the placement of the rods and how to stack them, is critical to create a large supporting area to keep the equilibrium. Also, she is aware of that the higher the tower gets, it is a greater risk that it will collapse as the centre of gravity shifts. Slanting-high is a technical concept that she invents since she needs it for her explanation. According to Vygotsky (1934/1999) it is only when the child has understood the meaning that it needs a concept. Concepts are used for explaining or understanding something. A short while after that she has climbed the chair to continue building, the tower collapses. She starts, with enthusiasm, to build another tower and when building her third tower she stacks the rods very carefully to get her tower straight.

Example 2. David (4:3) has less experience of constructing towers with Kapla rods. He gets inspired to join in and he studies Agnes and listens to her reasoning with the teacher about the importance of equilibrium and to build carefully, adjusting the rods all the time. David puts some rods aside and the

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[1] Kapla is a construction set consisting of identical wood planks

researcher (R) asks him why:

D: Uhh, so thick.
R: Why didn´t you take those rods?
D: They are not good. You can´t use them.
R: Why is that?
D: Because they are too thick...too *fallish*
A: They are too thick. Then it doesn't work, the whole construction could collapse.

Here David uses the concept *fallish (rasiga* Sw.) to explain to the researcher what will happen with the tower when building with rods of different dimensions. The tower gets unbalanced and the construction might collapse. David is talking about the function of the rods and he has created his own concept *fallish.* The meaning of this concept is shared between David and Agnes, which indicates that it is reflected over. The concept is created and connected to the activity of building to be able to communicate in the specific situation. It can be interpreted as a concept proper in Vygotsky's sense since David is able to verbalize what *fallish* rods have in common (that they are *too thick*).

Example 3. At the time of the study, an ongoing thematic work about dwellings was carried out in the preschool. In this example, three children are constructing house models. The preschool teacher introduced the children to some ideas how they could build and she presented what materials (such as ice cream sticks, flirting balls, cardboard, clothespins, rounds of juniper wood, round sticks) they could use. Tor (5:6) has decided to build a fairly large house of cardboard. When Tor starts to cut the cardboard with the small scissors for children, he has problems to get through. He tries to use both his hands but fails. After a while, he says: 'I´m not so *strong* with these scissors…'

His statement indicates an understanding of the function of the scissors, a two-armed lever. The larger the shears' legs, the more force there will be to cut. He needs more power to cut in the thick cardboard. The researcher then helps him to cut and they take a larger pair of scissors to help get through.

Here Tor uses the expression *strong* when he talks about the function of the scissors. He talks about something that corresponds to the concept of *force*. He does not say that the scissors are not strong, but that he does not become strong with the scissors, which shows an understanding of the tool principle and the technical content in the concept *strong* as Tor uses it.

Using Body Enactment and Everyday Concepts for Explaining Physical Motion

The examples under this heading are drawn from reflective dialogues where 18 children in a preschool class were asked questions intended to point out a problem that could be explained in classical mechanics and basic astronomy. The reflective dialogues were used to encourage the children to reflect on their use of language in their own explanations of what happened.

Example 4. In the sequence below, Ove (O) below was asked by the researcher (R) about what happens when he throws a ball slantingly up in the air. The researcher follows up the introducing question by asking about the reason for the ball to 'go up'.

R: What makes it go up?
O: That…I think it is the *force*, it has, sort of… like we take a force, as if we throw a pillow, then we have a force, as if we throw a pillow, then we have a force, and then, and so that, it just flies with that force, and then downwards…then.
R: Yes?
O: Because then, then, then, it doesn´t have such *away-force*, so just it goes down.
R: You say that it has no away-force. What is it that gives it, this away-force then?
O: I think, perhaps, here if you throw it, then maybe it, it here, so that you oouum (pointing at his arm muscle)
R: You mean that muscle…or?
O: Mm.
R: Aha, so it is the muscle in your arm that gives it force?
O: Mm.
R: Yes, this with force, what do you think of when you say force?
O: Force…almost nothing.
R: No? Could you have said it in another way, with another word?
O: No I can't come up with anything.
R: So it is what you think fits best, when we speak about throwing a ball slantingly up in the air?

O: Mm.
R: Yes. You said force and away-force. Is it the same kind of force?
O: Yes.
R: So all force is sort of away-force?
O: Yes all as if you have force to lift a table… and then you have the force here, like, and then it lifts upwards.

Ove uses the notion of *force* when he explains what causes the movement of a ball. The way he uses the notion can be interpreted as an everyday concept, in Vygotsky's sense. An everyday concept relates to children´s empirical experience and the consequences that can be drawn from experience. In the sequence, Ove is invited to reflect on this concept that he uses as an explanation for the movement of a ball. The explanation involves the idea that force is something given (from the muscle) to an object (like a ball), and then contained within the ball, maintaining its movement, until the *away-force* as he puts it, ends, and the ball falls down. This idea is consistent with Ove's experience of physical movement. The notion of *away-force* is his own concept, an aspect, or synonym of force. When he says that he means 'almost nothing' with *force* it can be interpreted that he has not reflected on his ideas. In his explanation, Ove uses, besides verbal resources, bodily and non-verbal expressions to make sense of the phenomenon.

Example 5. Evy (E) in the sequence below was asked by the researcher (R) about what happens to a ball that is thrown slantingly up in the air. Evy gets up from where she was sitting and starts to show the researcher how her understanding of how a ball starts to move, saying:

E: Yes, it goes up just because… I will show you on the floor…
R: Yes?
E: It goes up just because you do like this (mimic kicking a ball). You take it, it is so light so you can kick it, then it just flies and does what you want it to do.

Evy's explanation is almost entirely bodily when she makes sense of how the ball moves, something that applies to how Vygotsky denotes the *sense* of a word as the aspect that is personal, creative and something that 'enriches' meaning. The sense of a word also depends on the context where it is used. Earlier in the same dialogue when she told the researcher why she thinks that the moon is not falling down, she says that the moon is not falling because it is held by 'invisible tentacles', and in the extract below, she is asked about what she means with invisible tentacles:

E: …so they hold…for example, if this is the moon (shows with her hand), let´s pretend, then this is the globe, and then it seems small but it is actually giant… […]
R: Okay… you said the earth flies around…?
E: Yes, it is to say it flies here and there, without you noticing it, the earth spins…
R: Yes?
E: …around.

When telling the interviewer why the moon doesn´t fall, Evy uses her hand to explain what she means by the metaphor of 'invisible tentacles'. Using metaphors can be seen as a way to relate something new and partly unknown, to something that is more familiar (Pramling, 2015). Also, by using the words 'let's pretend' she makes it clear that she is speaking 'as if'. This indicates that she is aware that what she says should not be interpreted literally (as is). Through those meta-markers Evy communicates about the conceptual content in terms of something that is more familiar and easier to express. Later in the same sequence she speaks about phenomena that cannot be experienced with one's senses, like the movement of the earth or the 'actual' size of the moon: She says that: 'It seems small but it is actually giant….', which implies that she is aware that the moon can be experienced differently, depending on where it is viewed from. This can be interpreted that she is aware of the difference between how it seems and how it is, something that might imply that she is on the way of appropriating an abstracted, scientific conception.

Children's Reasoning and Use of Chemistry Concepts in the Space Between 'As Is' and 'As If'

The examples below come from dialogues with children who had visited a culture centre and attended a drama activity about chemistry. The children were subsequently interviewed about what they remembered, how they had understood the activity that they had participated in and what they thought that the activity had intended to illustrate. In the dialogues, pictures from the activity were used to create mutual ground for talking with the children

Example 6. In the following sequence, Kristoffer (K) was asked by the researcher (R) about a photo taken from above as the group of children acted as water-molecules that were mixed:

> R: There, what were you doing there?
> K: There we put on caps and then we became *water molecules* and then we pretended to be water molecules.
> R: Yes, and what did you do then, pretending to be water molecules?
> K: They were standing so close, in a round ring and then we were to walk around and move, room temperature, just moderately, moderately and then we walked around, around around and bounced and when we came to somebody, to glass…pane or another water-molecule, then we bounced in another direction.

Then Kristoffer is shown another picture by the researcher and asked if he can see 'what it is':

> K: It is when they hold in a round ring, the hands, and then it is us the children who move and collide into one another and bounce away in another direction.
> R: Aha. I have another Picture here, with some red hats, what was that, do you remember that?
> K: *Sugar molecules.*
> R: Do you remember why they stood that close, kind of?
> K: Because we were, because it…the sugar molecules they keep themselves… because our water was cold and then the sugar molecules moved slowly and then, and then they keep together because a piece of sugar is built by sugar molecules and then they were a piece of sugar and all the sugar molecules and the one that it was cold water, then it sort of took long time, then it held…so that they were stuck quite a long time.

Kristoffer identifies the picture of the children wearing blue hats in terms of here 'we pretended to be water-molecules'. Using the word 'pretend' shows that he is in on the premise that this activity is characterized by imagination (as if), and because of this should not be interpreted as how something is in some sense is (as is). Kristoffer's explanation also implicates that he has made sense of the relation between movement and temperature.

Excerpt 2: In the extract below from the same dialogue, Kristoffer was shown pictures from an experiment carried out by a character acting as a chemist in the drama activity, trying to show how molecules move by pouring a coloured sugar mix in water of different temperatures. Kristoffer was and asked about what the picture was showing:

> K: It became green.
> R: And what did it mean then, when it became green?
> K: That it had spread. And, it like water…the water was cold, then it becomes as a beam down, but if it was warm, then it becomes almost like a cloud… then it becomes almost like smoke.
> R: Do you know why that happened like that then?
> K: It was because the water was warm!
> R: Yes, you said molecule, what is a molecule?
> K: A molecule is a small, tiny, tiny, tiny, tiny, tiny… tiny, tiny, tiny part of something.
> R: Of what? What can it…
> K: Of just anything!

When speaking about the green coloured sugar mix that is squirted into the water, Kristoffer says that if the water was cold: 'then it became like a *beam* down' But if it the water was warm 'then it becomes almost like a *cloud*… then it becomes almost like *smoke*'. By using everyday phenomena and observations Kristoffer speaks about something that could be difficult to explain in other terms. He uses similes like 'beam', 'cloud' and 'smoke' and meta-communicates by using markers like 'as' and 'almost like'. Those markers indicate that he is aware that what he says should not be interpreted literally (as is). Through those meta-markers Kristoffer communicates about the conceptual content in terms of something that is more familiar and easier to express. When asked about the concept of molecule (that he himself introduced earlier in the dialogue) and answering that a molecule is a small, tiny (used eight times) part of anything, he shows that he is close to appropriate a scientific understanding of one aspect of the concept of molecules, that it can be seen as the smallest particle in a chemical compound or element that has the chemical properties of that compound or element, and that it is too small to be seen. Additionally, when Kristoffer states that molecules are 'parts of anything', this could be interpreted as he is generalizing over a set of cases and uses the notion of molecule as a concept proper in Vygotsky's (1998) sense.

Example 7. In the dialogue with Carla (C) after the activity, she reflects on what she said to the researcher when asked about her conceptions of *water* (R) prior to taking part in the chemistry activity. At that point she used the word *monopoles* denoting molecules.

> C: I remembered that I told you the last time that it was water 'monopoles' but it was *water molecules*.
> R: It is just water molecules that are…
> C: …no, there are sugar molecules, apart from that I don't know much more about molecules. There is a molecule in us that has been in the dinosaur, so there might be a water molecule from a dinosaur.
> R: Do you remember where we can find molecules?
> C: In the air, air molecules. And if water starts to boil it turns to mist that goes up in the air. They can go up there in the clouds and then they rain down.

When Carla speaks about molecules and states that she does not know more about molecules she shows that she is aware that that there might be more to know. In doing so, she has identified a learning gap, what is still not known to her. To identify learning gaps about something, can be particularly productive when trying to learn more. She understands that there are not just one, but different kinds of molecules, and she refers to as sugar molecules and air molecules, and she adds that there can be water molecules in the air as well. The way she uses the notion of molecule implicates that it is a reflected concept and that her experiences from the learning activity has supported her to appropriate the scientific concept of molecule.

Later in the same dialogue Carla was asked to reflect on the notion of chemistry, and if she knows what it means:

> R: Do you know what *chemistry* means?
> C: Chemistry is *surface tension*.
> R: How do you mean?
> C: Chemistry makes the water striders float.
> R: The water striders float? What are water striders?
> C: They are small animals living on top of the water. They have small feet and glide on the surface tension. When the surface tension disappears, they go down from the water…

Carla here answers, a bit surprisingly that chemistry is surface tension, which is consistent with an earlier experience from watching water-striders on an outing with her family. When she connects chemistry with surface tension she is making sense of previous experiences from different contexts and creates something new. This is consistent with Vygotsky's (1930/1995) view on imagination as the ability to combine and interpret different impressions, a mode of thinking. Carla's answers in this dialogue implies that she is on the way to appropriate a scientific conception of chemistry, as the study of how different substances are constructed and their properties and reactions.

Findings and Discussion

The aim of this paper was to contribute to the discussion of how preschoolers invent, develop and explore science concepts, related to preschool activities and to shed some light on how they do so. Children´s conceptualization has in previous research (eg. Åkerblom, 2015; Siry & Gorges, 2020; Siry & Kremer, 2011) been shown to be rich, dynamic and creative when they attempt to make sense of science, and when empirical examples are viewed through a lense of Vygotsky´s theorizing on concept creation, the findings can shed some light on how some pre-schoolers make sense and shape their experience through language.

The results show that children in some of the examples **invent** their own basic scientific concepts, like Agnes and David who are participating in an activity of building towers with building blocks, inventing concepts like 'slanting-high' for the relation between the height and inclination of a tower. When David uses the concept 'fallish' rods to explain that rods with different dimensions might cause the tower to collapse he uses a concept that is invented, but also shared by the other children taking part in the activity. When the children invent concepts they also, in addition to the use of verbal expressions, use sensory and bodily expressions, like David in the described example who shows with his body that the rod is not useful. Also, in the example when Ove shows how a ball is falling he uses bodily enactment, which have been showed by Siry (2011) as a critical aspect when children make sense of science. This example suggests that those concepts are invented by the children in the activity when they experience technology and share this experience with the other children. This is in accordance with Vygotsky's (1934/1999) insights that it is not until a child has understood its meaning that s-he will need a concept, and the concept can be expressed in any way, as long as it is shared with others. And, as the later Wittgenstein (1968) proposed, language meaning is experienced in use.

The results also show how preschoolers **develop** basic scientific concepts, like when Ove uses the concept of 'force' as an everyday concept (Vygotsky, 1934/1999) in his explanation to a researcher about what happens to a ball thrown slantingly up in the air. When using the concept, he relates it to his own experiences of balls being thrown and the consequences that can be drawn from his experience. The way Ove uses 'force' in a sense that is not consistent with the scientific concept, but can rather be seen as one of the steps of generalization until he will be able to use it as a scientific concept (Vygotsky, 1934/1999). Ove, like Evy in another example use, besides verbal expressions, also bodily and non-verbal expressions in the explanation. Evy shows in her explanation that she is able to distinguish between what can be experienced with the senses and a more general abstract way of conceptualizing. This is in line with other studies that show that young children often include a broad repertoire of multimodal and other signs so make their ideas visible (Åkerblom, 2015; Siry & Gorges, 2020; Siry & Kremer 2011).

In the empirical material, there are also examples of how preschool children **explore** basic scientific concepts through reasoning and reflection. In one of the examples, when Kristoffer is asked about how he experienced a drama activity about chemistry, he shows that he can distinguish between what in the activity is to be perceived as imagination – 'we pretended to be water-molecules' and what should be perceived as chemistry, the movement of molecules as an explanation of temperature. He is also using abstract metaphors and similes, indicating that those should not be interpreted literally. Also Carla reflects over the concept of molecules in relation to the experiences she made in the drama activity. The way Carla and Kristoffer are making sense of 'chemistry' and 'molecule' is consistent with Vygotsky's (1930/1995) writings on imagination as a mode of thinking and being able to combine different impressions. The way they children explore the concepts implies that they both are on the way to appropriate scientific concepts. Those findings are consistent with research by Siry and Kremer (2011) who highlight that children should be given opportunities to share their understandings through discussions in relation to science activities. Also, Pramling Samuelsson and Pramling (2011) emphasize the role of language and linguistic mediation of a child's experiences by a more competent partner, and the use of children´s different understanding as a resource and as a pedagogical principle. This is also in line with several studies where the usefulness of aestetic expressions is pointed out as a way for children to explore scientific knowledge (eg. Kalogiannakis et al., 2018; Güneş and Şahin, 2020; Ødegaard, 2003).

Conclusions

To sum up, the results of this investigation show that the children's elaboration to make sense of scientific and technology concepts appear as creative and sensible. The preschoolers are forming and sharing their own concepts, as well as using disciplinary concepts for problem solving and communication. The difference between the varying contexts bring light to the situatedness of conceptualization by young children. In the study about technology the children use concepts to make their insights about building common, in dialogue with their peers or teachers. It shows that concepts are closely linked to practice are created in the activities because they fill a concrete part, to be able to share them and solve technical problems together. Whereas the dialogues about physical phenomena between children and a researcher had a different purpose, that was to reflect over their own used expressions. The form of dialogues, where the interviewer shifted between asking about physical phenomena and about the language the children had used to speak about the phenomena provided another kind of insight in the process of conceptualization.

The conclusions for how children's concept development and scientific sense-making could be supported in early childhood settings that can be drawn from this very limited study is that central to science education in preschool is that the children are afforded with rich opportunities to use disciplinary concepts and create concepts themselves to make sense of scientific phenomena. The findings are consistent with Vygotsky's (1934/1987) conclusions that scientific concepts are not learned in final form, but develop, and Wittgenstein (1953/1968) that language meaning cannot be formulated at a general level, until/unless it is experienced in use. This means that conceptualization and development of abstract thinking is something that is experiential first; then becomes abstract. This means that, which is also highlighted in previous research, there must be science materials available and time to explore the materials in preschool settings (Saçkes et al., 2011), but also and maybe even more critical, there must be a joint understanding among the educators about the purpose of the science activities, and they should be able to frame the science content of children's experiences in a child-responsive way (Sundberg et al., 2018). Our study, and recent research (eg. Güneş & Şahin, 2020) also shows that children are more able to generalise and abstract scientific phenomena in a way that was previously not expected (Piaget, 1971). For the preschool teachers, a consequence of this study as stressed by Andersson and Gullberg (2014) could be that it is more important to provide a positive and permitting environment for the children, than avoiding to work with science and concepts due to lack of knowledge and insecurity.

This study contributes in particular to knowledge about children's concept creation that points at the importance that science education for preschool children should aim to create dialogic spaces where children, with the support of their teachers can invent, develop and explore science and technology concepts in a context where the phenomena are experienced.

Limitations and Implication for Future Research

Although this study has the potential to shed some light on children's conceptual development, it suffers from limitations as well. First, since the empirical material was drawn from studies with different purposes and not with the specific aim of studying children's conceptual development, the material could be difficult to analyze and information that would be interesting in relation to this study may be lacking in the material. Also, the study is very small, which means that the results are not in any way, conclusive. The way the examples were chosen, with the aim to show a rich material and examples of a variety of concept creation should be seen as examples with the purpose to discuss the matter of conceptual development. Therefore, implications for future research would be to make a larger study and to create the empirical material with the aim to answer the research questions from the beginning. For such a study, the present study could be seen as a guiding pilot study.

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Research Article

Follow the leader: Child-led inquiries to develop science learning of young children

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Abstract: Science education in the early years has been found to be lacking when compared to other content areas, specifically numeracy and literacy. It has been suggested that this lack of opportunity for young children to learn science is due to educator's lack of confidence to teach science, fuelled by concerns regarding a reduced understanding of science concepts. For young children, however, science is everywhere and is embedded in all aspects of their lives as they explore and interact to make sense of the world around them. Given this natural connection to science, it is important for educators to notice and respond to children's interest to encourage science learning to occur. This paper reports on an exploratory research study in which children took the leading role in inquiry-based interactions during off-site school days that took place within a metropolitan city zoo. Through the collection of observations and interactions with the research, several inquiries were documented. The children challenged the educators within the program to follow up on questions posed by them and engage the children across a broad age range in an inquiry to answer these questions.

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Introduction

For young children, science is part of their daily lives as they explore their surroundings and try to make sense of their world. It has been suggested that "as soon as children realize they can discover things for themselves, their first encounter with science has occurred" (Tu, 2006, p. 245). Unfortunately, however, educators who work with these young learners often lack both the conceptual and pedagogical knowledge to confidently teach science and as a result implement science learning using formal methods which lead to one-off teacher directed experiences (Gerde et al., 2018) that may be less meaningful to the children. Through an exploratory research approach using an interpretive lens, this study aimed to provide an alternative to these experiences, by allowing children to take the lead on inquiries and therefore, encouraging the educators to develop inquiries that align with these interests. The research took place within an off-site schooling program that engaged children, aged between 3 and 7 years, one day per week in visits to a metropolitan city zoo. It is hoped that these examples from practice will inspire others to firstly notice, and then follow children's questions in a shared learning experience focused on science, but that also incorporates other areas.

Young children are inquisitive and curious, and they learn through exploration with their senses and through asking questions of the adults around them. Research has found, however, that often these questions go unnoticed by educators in the early years which results in missed learning opportunities for both the children and the educators - "…it depends on the teacher's awareness, to bring science to the surface, to make it visible for the children, because if they're not made aware, then it will pass and it doesn't go anywhere" (Campbell et al. , 2015, p. 21).

This lack of noticing can be caused by a number of factors including: lack of time in a busy early years' environment; priority being given to other learning areas, such as numeracy and literacy; or educators lack of science content knowledge to firstly identify the science opportunity, then confidently

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follow this science learning opportunity through. In a widely cited study in 2006, Tu identified that while 50% of the classrooms he visited contained a science area, 86.8% of the activities completed within the classrooms were not science related. There were no instances of incidental teaching of science and even when plants were present in 70% of classrooms, these were not there for science-related purposes. This led to the conclusion that "preschool teachers did not provide adequate science activities and preschool teachers also missed teachable moments" (Tu, 2006, p. 251). Similar research by Saçkes et al. (2011) also identified that science learning was not typical in early childhood classrooms. Both Tu (2006) and more recent research by Edwards and Loveridge (2011) called for "teachers to rethink the purposes and practices of science teaching, inferring the importance of reflective practices" (p. 30) in examining why science may be missing.

It has been identified that early childhood teachers lack confidence in teaching science to young children (Edwards & Loveridge, 2011) or lack self-efficacy in science teaching (Oppermann et al., 2019). Studies identify that teachers in early childhood settings may not be predisposed to teach science (Reinoso et al., 2019), may not have had exposure to enough science-based courses in their training (Saçkes, 2014), or lack of confidence in planning and demonstrating some science topics, which reduces focus in these areas (Oon et al., 2019). It is this lack of confidence that inhibits the noticing of science learning opportunities within early years classrooms and is why this research focused on following children's questions as the starting point for inquiries rather than relying solely on educators to plan the tasks.

Research has similarly identified that early years' teachers lack the appropriate level of content knowledge to teach science concepts and skills (Barenthien et al., 2018; Brenneman, 2011; Nilsson & Elm, 2017). Science concepts may be seen as difficult to understand (Abdo & Vidal, 2020), as may be the underlying constructs related to the Nature of Science (NoS) itself as a starting point for teaching young children (Akerson, 2019). While the science concepts in the early years often relate to the biological sciences as children explore their natural world (Larimore, 2020), subject areas such as chemical or physical sciences may be seen as more difficult to understand and teach (Abdo & Vidal, 2020) despite being significant in young children's sciencing of the material world (Areljung, 2019). There may also be confusion that young learners cannot understand concepts when, in fact they can, but they are unable to articulate this understanding. (Saçkes, 2015). Teachers who feel inadequate in their science knowledge may lack efficacy (Oon et al., 2019) to adapt content to the early years (Akerson, 2019) which is another reason to rely on the children's questions in setting the inquiry focus as they guide what they are interested in and the types of content that could be explored. The teachers can then complete research within the areas identified by the children to ensure they are learning concepts they can engage the children with at the appropriate level.

In addition to knowledge of content, knowledge is shown to be lacking in the pedagogical strategies used to teach science (Abdo & Vidal, 2020; Afifah et al., 2019; Areljung, 2019). Lee Shulman (1986) is recognised as being one of the first to identify that effective teaching requires not only content knowledge (CK) but pedagogical knowledge (PK) which is significant in planning for science if either of these are lacking. Researchers since Shulman have used the concepts of content and pedagogical knowledges to examine educator's abilities within these domains (Nilsson & Elm, 2017). Teachers have been found to lack these two distinct types of knowledge and while some studies have focused on improving knowledge, there may still be a lack of confidence in utilising the full range of science teaching methods in early years' environments. These findings further support the following of children's leads in teaching science as the children can help to determine not only what they want to learn (the content) but also be engaged in deciding how they want to learn it (the pedagogical strategies). The children can ask to read books, to search the Internet, to ask an expert or to try an experiment as part of their inquiry. The educator can follow this idea through, to provide the required resources for these explorations to happen and be adding strategies to their repertoire along the way.

Based on these identified concerns for educators in teaching science, and the natural connection young children have to learning science, this exploratory study set out to identify:

- If child-led inquiry focused on children's interest led to the learning of science concepts; and

- What role the educators had in these inquiries as a model for improving science teaching in the early years.

To explore these questions, the researcher worked with one community-based school setting where the children attend off-site schooling one day each week.

Method

The research reported here, utilised an exploratory research approach where the focus was on collecting large amounts of unstructured information to then interpret and discuss (Check & Schutt, 2012). The exploratory approach was chosen as the researcher had an idea of what would happen during the research (based on experience of off-site school) but had "no clear expectation of what to expect" (Cohen & Manion, 1994, p. 259). The goal was not to prove or disprove a hypothesis but to identify the roles played by the children and the educators in the process of learning science concepts (Cohen & Manion, 1994). Through an interpretive lens, aligned with participatory research methods (Denzin & Lincoln, 2011), the research explored the interactions of children aged between 3 and 7 years, and their educators in an off-site schooling program to examine the social constructions of science learning that were being established (Check & Schutt, 2012). As the researcher was known to the educators and the children, they were able to engage in participatory observations of the normal activities that the children and educators undertook during their visits to the metropolitan zoo as part of their regular off-site schooling program. The data were collected through a range of observation methods and the inquiry projects were reviewed for the interaction patterns that developed from the children's questions, answers, and explorations.

Participants

The school that hosted this research is a community school that has a focus on Science, Technology, Engineering, The Arts and Mathematics (STEAM) learning and inquiry. The school caters for children from pre-kindy (3 years old) through to Year 1 (6 years old) and incorporates an off-site schooling day each week with the setting changing each school term. Previous off-site days have been spent in local parks, alongside the river and a science centre. On the off-site day, the parents either deliver and collect the children from the external site or the group meets at the school and utilises spaces within walking distance of the school or catches public transport to visit specific sites. This study engaged with the children as they spent a term visiting the metropolitan city zoo that was close to the school and facilitated parents dropping off and picking up from the zoo site.

The off-site group consisted of 12 children each day – 7 in Kindy (4-5 years old); 3 in Pre-Primary (5-6 years old); and 2 in Year 1 (6-7 years old); with 2 teaching staff each day although four different educators across the term. The educators held early childhood teaching qualifications so were generalist teachers although the focus of the setting meant they had completed professional learning on a range of science concepts and the inquiry process. Three different parents also joined the group on separate observation days. These parents were professionals in their fields although none with a specific science focus – one was in marketing, one in law and the other ran his own business. The sample was selected based on school enrolment patterns, staff rosters and parent availability to attend on that particular off-site school day.

Informed consent for engagement in the research was provided by the principal, the educators and the parents of the children enrolled on that day within the school through a signed consent form at the beginning of the research project. Assent was also given by the children within each interaction before notes were made or photographs were taken to ensure they were willing to be involved in the data collection for the project. This was a verbal agreement between the children and the researcher at the time of the observation or conversation taking place.

Data Collection

The data collection for this project utilised a mixed methods approach based on participatory methods of observation and discussion through interactions with the children and adults as they explored their zoo inquiries. The documentation of these observations and interactions took multiple forms within the research process, including field notes, reflections, photographs, and educational documentation.

- Field notes were taken of the questions the children asked and the responses given by the educator and researcher during the time spent exploring the zoo. All children engaged at least once across the observation period with these data collection processes.
- Photographs were taken of the children interacting in inquiries as well as of the Floorbook© pages that documented these inquiries during and after their implementation.
- Reflective notes were made of discussions with educators throughout the observation times and between visits when they wanted to discuss possible avenues for future inquiries based on the previous visits. The teaching staff varied in knowledge, skills, experience, and confidence in teaching science to this age group of children and as such, a culture of mentoring and ongoing learning was present within the staff team
- Additional reflective notes were taken of discussions with some parents who attended zoo kindy as a volunteer helper on some of the observed days. These often included questions about the philosophy of the inquiry-based program and why it was valued by the school.

Data Analysis

There were substantial amounts of qualitative data collected and documented through the observations and interactions completed on the zoo visits. Analysis of the data began with the identification of factors based on "a hunch to the factors that might emerge" (Child, 1970, cited in Cohen & Manion, 1994, p. 331) to examine the structures and relationships connected to the human experience (Cohen & Manion, 1994). These initial factors were initially identified as (1) questions, (2) interactions, and (3) resources. Using these. factors, the data were sub-divided for descriptive analysis (Denzin &Lincoln, 2011). As the focus was on interpreting the specifics (Cohen & Manion, 1994) and relationship of these factors, the decision was made to review and present the findings in relation to the individual inquiries and how these factors were present in each.

Results

Across the term of observations with the children as they attended zoo kindy, multiple inquiries were undertaken based on questions from the children and interactions with the educators. For the descriptive discussion as results of this study, each inquiry is considered as a unique case and the data were reviewed with the factors of questions, interactions, and resources towards the research questions. A total of four explicit inquiries are reported on in this paper from across the term with some lasting for one visit, while others built upon learning from a previous visit to inform a future interaction – sometimes across several weeks. Several additional inquiries were also completed across the term of visits to the zoo and while these were valuable, they are mentioned as one block rather than detailed as a unique inquiry due to less plentiful data or less children being engaged.

Inquiry 1: "The Rickety Bridge"

Each week at zoo kinder incorporated a 'human vote' where the children would vote by physically posing as the attraction they most wanted to see first. The results of this vote then determined the journey to be taken as the group moved around the zoo on that particular visit. Across the first weeks of zoo kinder, the older children convinced the younger children that based on their prior experience, (they had experienced zoo kinder the year before) the Rickety Bridge was the best place to visit and should be completed first.

The Rickety Bridge was erected across a waterway that flowed down through a bushy section of the zoo, and as the name suggests, it was a bridge that moved as you went across it. The *questions* associated with this zoo attraction related to the materials used in constructing the bridge - rope, nets, wood, steel string; and how these materials led to the rickety nature of the crossing – it was hung from trees and posts rather than being fixed to the ground across the middle because there was no ground – just water.

Some of the younger children were very unsure of using this bridge to get across and this led to *interactions* and investigations related to the 'secret path' that went behind some bushes and around a different way to avoid crossing the rickety bridge. The children discussed why the secret path was there – for safer trail through the bush, to avoid the bumpy bridge, for prams and trolleys to use, and to show different plants.

On one visit after the rickety bridge had already been explored as the first stop, the group came across some workers constructing a new wooden bridge to get to the elephant viewing platform. The children again engaged in further discussions, this time comparing the materials being used for this bridge – different types of wood; and how this construction differed from the rickety bridge – it was fixed to beams that ran along the floor. This bridge was described as heavier because it was made of wood. This fixed design was considered much more appropriate for this bridge that had many more visitors accessing this area than the rickety bridge's bush and there was no water to get over that needed the bridge to be suspended.

Connection to Research Questions

This inquiry demonstrated the link to the children's interest that led to science learning that was facilitated and supported by the educators. The learning for the children in this inquiry related to the properties of materials in terms of what to use in what situations as well as the engineering required for bridge design and the bridges being fit for purpose. Comparison of plant life was also completed as the group of younger or less confident children avoided the rickety bridge and there was discussion of surfaces best suited for different types of zoo visitors and what this diverse group needed. The interactions with the educators extended the children's thinking beyond the simple materials used to create the bridge to the engineering concepts that required the bridge to be constructed as it was. Questions were posed, particularly when compared to the 'other' bridge about why these materials? Why this design? The group that was less confident on the bridge were less engaged with this inquiry, but the older children did connect this to other experiences and led into the future inquiries back in the classroom in physics. No additional resources were required in this inquiry although the design of the bridge was documented in the Talking and Thinking Floorbook ©

Inquiry 2: "The Reptile House"

On a different day at the zoo, the children voted to visit the reptile house. Within this area, there is a glass fenced enclosure in the centre of the room that houses numerous Australian lizards that can be seen by the children at floor level. There are large heat lamps hanging from the ceiling and the lizards often congregate under these. From previous visits to this area, the 6-year-olds were able to tell the younger children that the lizards were in these spots because it was just like lying in the sun which the lizards did to "warm their body temperature". As these lizards moved around, there were a range of tracks being made on the sand floor and a group boys began trying to follow the tracks to identify which lizard had made each unique track and how these were made. Feet and tails were identified as the tools used in track making and so the width of tail and size of feet made a difference. "Mr Lizard is making a trail (squiggly lines) with his tail" was the conclusion.

Also, within the reptile house, there was one snake in a glass case fixed into the wall that was long and sleek except for a large bulge in one section at about the middle of the snake. The provocation was "I wonder why there is a big bulge" to which a 3-year-old responded that "the tummy has gotten bigger because the snake had eaten too much dinner". This led to discussion of what the snake could have eaten, and the group used the information chart on the wall that detailed diets of reptiles. From this, it was decided that it was probably a bird, but a small one like a willy wagtail not a big one like a magpie.

In another glass enclosure within the reptile house, there was a snake who was in the process of shedding its skin. One 4-year-old was particularly interested in this and concerned that this shedding process was painful to the snake. He had enough confidence to approach a zoo volunteer to ask if this process was painful to the snake and was relieved when the zoo helper reported that it was not. The discussion further ensued about what snakes ate and after initially guessing leaves, the discussion moved to name mammals as the snake's main food source and further conversation about what a mammal was and how it was different to a reptile who laid eggs and were cold blooded. The 4-year-old then asked how the reptile kept warm, and the volunteer pointed out that in their natural world they lived underground then came out to the sun to warm up, but in the zoo, they had the heat lamp which the volunteer then pointed out to the inquisitive child. The discussion between this child and the volunteer rounded out with confirmation that the snake used the heat to warm up enough so they had energy to hunt. This discussion made an impression on this young learner as the child was able to recall much of this learned information in the following week when he returned to the reptile house.

Connection to Research Questions

Biological sciences were the focus of these interactions and through follow-up questions deeper learning occurred. By revisiting the reptile house again in future visits, it became clear that the inquiry was led by the students and the learning that happened within these interactions was being retained by the young children as they could recall the content learned through the previous interactions. This allowed them to extend their own inquiry each time they returned to this environment. The reptile house provided several small child-led inquiry cycles to be implemented where the children identified the *question* and then identified *resources* available to find out the answers to these questions. While on some occasions the educator *interacted* to provide prompting questions, at other times the children utilised other *resources* such as the information charts on the walls within the reptile house or the zoo volunteer to answer their inquiry questions. The confidence to not rely on peers or teachers allowed for more detailed discussions of what the children were interested in by accessing 'experts' that were available.

Inquiry 3: "Waterproof or not"

A favourite part of each zoo visit was not related to the animals. The playground area adjacent to where the children had lunch incorporated a man-made stream where the water was pumped from a large ceramic bowl that filled and then created a waterfall at the top of the hill. The water then flowed through a curving channel to the 'pond' at the bottom where the water flowed into a grated drain and was recycled back to the top. The children loved getting completely drenched within this area before getting changed to do one more animal visit or complete the Floorbook© documentation before going home. The play within this stream area opened possibilities for several inquiries connected to water and water use but the fact that the children's clothes kept getting wet, led the children to ask questions about clothing selections and discussions that they should wear clothes that were waterproof – but what did this mean?

The resulting waterproof inquiry ran over several weeks and incorporated numerous individual explorations. On one visit, based on the children's lack of understanding of what materials were waterproof, the educator provided a bag of fabric scraps to the children who subsequently explored which pieces were waterproof or not. Initially, there was a great deal of misconception about what waterproof meant, especially among the 4-year-olds. Several the children submerged the material into the water and claimed, "its waterproof" and when asked why, they detailed "because it got wet". The distinction some children made here was they described it as getting wet but not soggy as soggy things were not waterproof. One of the 5-year-olds came in at one point during the exploration and said that waterproof meant it helped people not to get wet – like a raincoat, while a 6-year-old added that waterproof things can go in the water and not get wet. This provided the language for the children to use in their inquiry practices. After further exploration, the 4-year-old then explained that some materials were not waterproof because they got wet in the man-made stream. This exploration clearly identified the developmental continuum at play within these open-ended inquiries and allowed the younger children to learn from older peers who were able to articulate what waterproof meant and this altered the younger children's understanding of the concept. This learning was led by the children and although the educator provided the materials (*resources*), it was the *interactions* among the children themselves that facilitated the learning.

To further develop the concept of waterproof in a future week, the educator took a large roll of paper, a roll of clingwrap and a roll of aluminium foil to the zoo. During the visit, the children engaged with making boots out of the different materials to see which ones were best in keeping their feet dry. This exploration extended upon the concept of waterproof but also related the learning to children's own experiences in terms of wearing boots and demonstrating the connection between learning and the children's everyday lives – an important process in helping children to see the purpose in their learning. The teacher-directed *interaction* utilised additional *resources* based on the children's *questions*. While there were issues with the design and construction of the boots – mostly related to the nature of the materials and difficulties with construction, the children were able to determine that the paper was the least effective material for boots, and the plastic wrap the most successful material to use when making boots to keep feet dry. The children also identified from this that this was why gum boots from the shops were made of plastic although they did acknowledge the plastic of gumboots was thicker than the cling wrap to effectively keep feet dry in the rain.

At the top end of the stream, the children were also experimenting with stopping the flow of water from the waterfall/fountain at the top. On one visit, a 4-year-old boy spent most of the time allocated for the playground sitting in the bowl the water would flow from so that his bottom and legs blocked the stream of the water. This action meant the bowl collecting the water for the waterfall would fill to overflowing. He would use his arms to push his body up which would allow the water to flow in a rush "through a tunnel" and then he would drop down and block it off again. In discussion and through experimentation, he tried other body parts to block the flow of the water– his hands, his feet, his arms, but he identified that the bottom was the most effective as it slowed the flow of water to almost nothing. This led to a game where he would sit and wait until the bowl was full and then release the water in a rush and see how that impacted on his friends playing in the water further down the stream.

Connection to Research Questions

In this inquiry, there were several points where the educator had a direct role in facilitating the inquiry. Following from the children's interest in the water, and the problem of wet clothing, they provided additional resources and planned specific interactions to extend the children's thinking on the concept of waterproof. The different levels of understanding among the children meant that the inquiry had a broad scope but the interactions among the older and younger children allowed the shared learning to occur. The interaction with water allowed for chemical science explorations in terms of the properties of materials as well as technology related to choosing materials fit for purpose. The misconceptions about waterproof were corrected through interactions among the multi-aged group with older children supporting the learning of the younger ones. Water allows for a great deal of topics to be examined and many open-ended explorations to take place.

Inquiry 4: "What do they wear?"

The final distinct inquiry being detailed in this paper was the work the children did in relation to the coverings on the animals they visited. Across several weeks of visiting the zoo, the children discussed whether animals were covered in fur, feathers, skin, or scales and why there were differences. The children identified that scales allowed heat to be absorbed through the skin, fur kept animals warm, the shells of the tortoises kept them safe, and the feathers on the birds were a light covering so that the birds could fly. The children documented the animals by body covering in the Floorbook© and regularly enjoyed a game of musical stop just inside the zoo entrance where a play area incorporated large concrete pipes painted to represent different coverings of several animals, for example a zebra, a cheetah, a snake. Through the game, the children had to identify what the covering was that they had selected to sit on when the music stopped, which animals had this covering, and sometimes why this was the best covering for that animal. An extension of this initial inquiry with some of the older children was to discuss the colours of the coverings too and identify why different animals had specific colours and patterns. This was highlighted when the group identified that many African animals – the painted dogs, the tiger, the giraffe, had patterned fur to hide in the grasses and jungle areas.

Connection to Research Questions

The musical stop game allowed the educators to reinforce, in a fun way, the work completed in the

Floorbook© on animal coverings and the reasons behind the type, colour, and patterns of these. The children's inquiry started with questions about why animals had different coverings and the specific focus was determined by their preference for particular animals but also their understanding of climate, habitats and species of animals, depending on their age and interest. The use of the provided resource allowed connections to be made by the children with minimal additional resources being developed by the educators. These resources instead provided for alternate interaction patterns.

Different environments were identified as a key determinant of the type of covering animals had both in terms of type and colour. The biological concepts were learnt as the children explored why different coverings were more suitable in hot or cold climates as well as how coverings protected animals in terms of camouflage or physical environments. This learning occurred across multiple zoo visits and was reinforced through many other inquiries - the reptile house, the water play, and the elephant encounter.

Other Inquiries

While these four case examples are more detailed interactions of the learning that occurred under the children's direction, there were other inquiries across the term of zoo kindy. These included discussion of why emus had long strong legs and what the role of the short wings were – to turn when running fast; how the tortoise was eating the leaves, especially when the zoo keeper was using what looked like a toothbrush to sharpen the animal's beak; what nocturnal means and how the building in the zoo enabled the animals to be seen during the day; why the baboons have red bottoms which is of course hilarious as any talk of bottoms is; how to keep the zoo area clean, including litter, plant materials and most importantly what does the zoo do with all the poo? In case you wanted to know the answer to that last question, they share it with local councils and other organisations to be used as compost in gardens.

What was identified through these inquiries was the role of the *questions*, both from the children and the educators, to connect children's learning with other inquiries and other ideas. Sometimes educator *interactions* provided direction to the children to extend thinking or offering additional *resources* to answer increasingly complex questions. Very little was added to the environment by the educators and the process of following children's questions proved to engage all children in learning across the term of visits.

Discussion

The inquiries detailed in the results section demonstrate the ability of young children to learn a range of science (and other subject area) content through their own inquiries. The educators interacted throughout these to assist in answering questions and seeking out resources to support the children's developing understanding. Much of this was done based on the children's own interests and questions so they had control over what they were learning and investigating. Throughout this process, the educators were able to follow the children's lead, which reduced the pressure on the educators to identify areas for inquiry or to plan expansive activities that may have not related to the children in terms of age, interest, or current knowledge. The closing section of this paper focuses back to the research questions to provide support for the pedagogy of following the children's lead as well as encourage educators to embrace early childhood science from this child-initiated inquiry perspective.

Can Children Learn from Child-Led Inquiries?

The examples presented as cases within the results section demonstrate that child-led inquiries can provide a multitude of learning opportunities for young children. The inquiries developed from experiences the children were engaged in through hands-on processes where they could ask questions and work towards identifying answers,

The multi-age context allowed additional interaction and scaffolding of learning where younger children learned from their older, more knowledgeable peers and through this, misconceptions were clarified. The inquiries being undertaken were largely owned by the children which resulted in them being at an appropriate level of difficulty and focused on topics of interest. As some of the older children had experienced the zoo setting in previous years, they had already mastered these concepts and moved to more complex ones. The open-ended nature of the inquiries meant that the children could step in and out of inquiries at their current level and then be extended incrementally by more learned peers – it was Vygotsgy's Zone of Proximal Development (cited in Tudge, 1992) in action.

When the children were responsible for developing the questions and the focus was on their inquiries, they determined how to best adapt concepts to their developmental level (Akerson, 2019). While much of the content covered across the term related directly to the biological sciences and the natural world (Larimore, 2020), there was some exploration in other science areas as well as other subject domains. The inquiries were meaningful to the children and authentic as they controlled both the content and the process which is empowering to them and allows them agency over their learning (Duncan, 2018). The retell of experiences on subsequent visits and documentation of the inquiries demonstrated the learning that was taking place for each child as they engaged with these inquiries.

What Role Does the Educator Take in Child-Led Inquiries?

The main role of the educator throughout these inquiries was to ask prompting questions and to scaffold the inquiries identified by the children. The multi-aged groups and the peer social learning that was happening allowed the educators to deepen their understanding of the different stages of the learning of certain concepts through interactions with individuals and small groups to effectively facilitate and scaffold the children's learning across these stages.

The process of following children's questions was also beneficial to the educators, particularly those with less experience with inquiry because interactions enabled them to relax and let the children problem solve for themselves. An example of this was the waterproof inquiry with one of the newer staff members. She had decided to bring the fabric scraps to the zoo for the children to engage with the experiment about what was waterproof, but during the exploration was unsure when to step in and if they should be providing the correct answers to the children or not. Through providing the children with the resources and the time, the educator was able to observe the children's problem solving and eventually the older children supported the learning of the younger ones. This alleviated the concerns on how to effectively describe what waterproof meant at a level the children could understand and allowed the educator to engage without having to be the expert in the situation. The interaction improved her confidence and self-efficacy (Oon, et al., 2019) around this concept and led to her next scaffolded experiment with the paper, foil, and cling wrap to create boots to keep feet dry.

By having the children take the lead, the educators were able to complete additional research and scaffold explorations to meet the needs of the children, but the process also assisted in identifying what content knowledge was required (Abdo & Vidal, 2020). In addition to this, the focus on the children's questions including allowing them to decide how to answer the questions, decreased the reliance on the educators pedagogical knowledge (Afifah et al., 2019). This allowed the educators to be co-learners in the process (Henningson, 2013) and engage with the inquiry with more confidence, rather than being the director of the learning and working with limited strategies.

An additional role of the educator was in relation to the provision of resources. While the. zoo environment itself provided many of the resources for these inquiries with little additional required. The more teacher-led inquiries such as those related to waterproof materials saw that the educator scaffold the experiment with the provision of firstly a bag of materials and secondly the paper, foil, and cling wrap to create boots to keep feet dry were really the only additional resources added too inquiries. The child-led inquiries mostly used what was already there including displays, such as the reptile house inquiry, where the children utilised the information posters available as well as the zoo helper's expertise to answer their questions and were satisfied with that.

The documentation was the other area where the educators added materials and other supports to the reporting elements of the inquiries, but again the children completed this in their own ways and often took over the process. Their voices came through in the reporting of inquiries and this is an important part of the inquiry process (Duncan, 2018).

Conclusion

The examples provided throughout this research have highlighted how much children can learn when they are given agency over their learning and are provided with the resources to make connections and apply their newly acquired knowledge into alternate contexts across numerous weeks of visiting the same setting. The depth of inquiries and the development of the educators' science educational abilities throughout this process was also an outcome of the engagement with the zoo inquiries and provides support for the approach to be more widely implemented.

The findings of the study support the implementation of child-led inquiries through multiple interactions within diverse contexts and demonstrate that repeated visits to the same location are important not only for children but the educators as well. By having the opportunity to revisit the site, the children could explore more deeply on each visit and reinforce their learning. The educator was also able to prepare based on previous interactions for additional facilitated discussions and resources.

Additionally, the findings support the interaction of children across multiple year levels where older or more experienced peers can support the learning of others and assisted the educators in mapping learning and will enable them to provide further scaffolding in future inquiries. Research into this model and these processes will continue and is planned to involve additional educators and learning sites to further support the use of this process both within this school context, but also outside of it. Further research will provide additional examples for other educators within the field of early childhood and primary school science in relation to how child-led inquiries can effectively support not only young children's science learning but the development of educators' content and pedagogical knowledge and confidence to effectively teach science in the early years.

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Research Article

Exploring relationships between playspaces, pedagogy, and preschoolers' play-based science and engineering practices

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Abstract: This manuscript reports the results of a research study exploring the ways in which physical space and teacher pedagogy are related to preschoolers' engagement with science and engineering practices while at play. Using the Science and Engineering Practices Observation Protocol (SciEPOP), researchers captured children's engagement with the eight science and engineering practices identified in the Next Generation Science Standards (NGSS). This study explores relationships between specific playspaces, materials, and pedagogical strategies, and children's patterns of engagement with particular science and engineering practices during free play. There are notable differences in the spaces, materials, and pedagogies children encounter across the four participating preschools, and these differences suggest significant gaps in children's opportunities to engage in and deepen their enactment of science and engineering practices. The authors present evidence in support of adaptive, personalized strategies for deepening children's engagement with science through play, and raise questions about equity in early science learning environments that have implications both nationally and internationally for science education research, practice, and policy.

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Introduction

Children are natural scientists and engineers, exploring and manipulating the world around them (Cunningham, 2017; French, 2004; Gopnik, 2012; Greenfield et al., 2017; National Academies of Science, Engineering, and Medicine, 2021; National Research Council, 2007; Trundle, 2015; Trundle & Saçkes, 2012), and building understanding about that world through their interactions with others (Vygotsky, 1978). While children's play has long been recognized as critical to their learning and development (Akman & Özgül, 2015; Bonawitz, et al., 2011; Nayfield et al., 2011; Ross, 2013), little research has been done to document the ways that children engage in science learning through self-directed play. Instead, science in the early years is often conceptualized as necessarily directed by an adult and structured around a particular table or "station" in a classroom (Tu, 2006; Vitiello et al., 2019). This conception of early childhood science learning fails to account for the creative and intuitive ways that children engage with science as they interact freely with both indoor and outdoor playspaces. Even this teacher-directed science instruction is rare in early childhood education (Early et al., 2010; Piasta et al., 2014; Tu, 2006) and is particularly rare in classrooms serving low-income communities (National Research Council, 2007), specifically including Head Start settings in the United States (Gerde et al., 2018). This disparity in science engagement among low- and higher-income children leads to differences in science knowledge beginning as early as kindergarten, and it is a disparity from which lower income children rarely catch up (Morgan et al., 2016).

Though most states and nations have standards for primary and secondary science education, preschool educators often have little guidance around what science to teach or how to teach it. Add to this the persistence of low science self-efficacy and sparse science content background reported among early childhood educators (Barenthien et al., 2018; Gerde et al., 2018; Greenfield et al., 2009; Saçkes, 2014), along with a nearly ubiquitous focus on literacy and math in preschool curricula, and the result is often that

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preschool-aged children get little to no formal exposure to science. Further, the mere presence of science-related materials does not ensure children or teachers will engage with those materials through science and engineering practices (Fleer et al., 2014; Tu, 2006). In other words, the context (i,.e., playspaces and pedagogy) influences how children play.

This study addresses a significant gap in the literature around early years science learning by developing and using an instrument (the SciEPOP) to identify scientific and engineering practices in children's free play, characterizing those practices at multiple levels of sophistication, and accounting for pedagogical strategies or "teacher moves" that support or disrupt those engagements. In this manuscript, we offer empirical evidence that children at play are engaging with all NGSS-identified science and engineering practices (SEPs) at emergent and progressively sophisticated levels in a variety of school and care contexts. By focusing on playspaces that vary significantly in the types of materials, outdoor space, and access to the natural world available to children, we identify place-based elements that are associated with SEPs engagement. Further, we present an analysis of the pedagogical strategies that teachers use while children are engaged with these SEPs, paying particular attention to the patterns specific to strategies that facilitate or hinder play. Finally, we identify the implications of these findings for early childhood professional development, teacher practice, and research and evaluation purposes.

Science and Play

The role of play as a fundamental component of child development is recognized internationally (Gomes & Fleer, 2019; Howes & Smith 1995; Norðdahl & Jóhannesson, 2016; Pellegrini & Nathan, 2011; Weldemariam 2014). In fact, the *United Nations Rights of the Child*, article 31 explicitly states that play is the *right* of all children (1989), and the National Association for the Education of Young Children's (NAEYC) Code of Ethics (2005) explicitly states support for "children's development and learning; respecting individual differences; and helping children learn to live, play, and work cooperatively" (p.2). This central focus on collaboration and play in early childhood learning environments creates context for what Ross (2013) argues are "parallel processes in both individual and cultural learning"; but while play remains central to the curricula in many preschools, what little science learning happens in early childhood education (ECE) is often teacher-directed and structured around a particular table or "station" in a classroom (Tu, 2006; Vitiello et al., 2019).

This conception of early childhood science learning as a discrete activity happening at an assigned "station" fails to account for the rich experiences afforded when children interact freely with their natural environment. Further, some studies suggest that children's scientific process skills are better developed through exploratory and self-directed play than through direct instruction (Bonawitz et al., 2011; Bulunuz 2013). These early experiences with self-directed and collaborative science play may not only help children construct their own ideas about the natural world but may also help them develop a sense of agency and science identity (Barton & Tan, 2009; Barton et al., 2013; Cunningham & Carlsen, 2014), factors related to persistence in the study of science and engineering.

The release of the Next Generation Science Standards (NGSS) in the United States, a standards-based reform effort, has renewed focus on fostering science learning in early childhood and has given researchers and educators language with which to articulate children's engagement with science during play. The NGSS includes three critical and interdependent "dimensions" of learning: Science and Engineering Practices, Core Disciplinary Ideas, and Crosscutting Concepts (NGSS Lead States, 2013). This shift towards three-dimensional science learning emphasizes "figuring out", by engaging with science and engineering practices to explore phenomena, versus simply "learning about" what is already known (Schwarz et al., 2017). This approach to building science knowledge by "doing" the work of scientists and engineers (Lachapelle et al., 2013) has the potential to mitigate some of the historical tensions between the more individual, cognitively-focused goals of science education and the "whole child" approach of early childhood education that places equal emphasis on cognitive, affective, and social learning goals (Larimore, 2020).

This shift is laudable; however, existing observation protocols do not adequately capture the variety and depth of children's engagement with SEPs in play-based learning environments. In response to this need, the authors developed and validated the Science and Engineering Practices Observation Protocol (SciEPOP) - a tool benchmarked to the NGSS Science and Engineering Practices (2013) (Appendix F) and designed to support teachers, administrators, and researchers in the characterization of these practices in early childhood. The SciEPOP allowed researchers to explore a critical research question: How are early learning playspaces and teacher pedagogy associated with preschoolers' developing science and engineering practices in play-based learning?

Method

Instrument Development

The SciEPOP was developed in response to a clear need in this field for student-centered observation instruments. Existing tools focus primarily on teacher practices and do not account for children's science practices in these interactions. Early years observation tools including the Preschool Teacher Verbal Interaction Coding Form (Tu & Hsiao, 2008) and the Systematic Characterization of Inquiry Instruction in Early LearNing Classroom Environments (SCIIENCE)(Kaderavek, et al., 2015) focus on teachers and not the role of children and children's play in the teaching and learning. Tools at the elementary level such as the Reformed Teaching Observation Protocol (RTOP) (Piburn & Sawada, 2000; Sawada, et al., 2002), the Inquiry Science Observation Coding Sheet (Brandon et al., 2008), and the Practices of Science Inquiry Observation Protocol (P-SOP) (Forbes et al., 2013) have similar purposes.

In response to this lack of validated instruments for observing children's engagement with SEPs, Miller & Saenz (2019) developed the SciEPOP through an exploratory pilot study and an instrument validation study. The SciEPOP was developed and validated (Saenz & Miller, in process) using pilot data and classroom observations from one of the four preschools participating in a larger ongoing research project. Initial development and revision of the instrument was based on more than 20 hours of observations, as well as the aforementioned review of existing instruments, and literature rooted in early childhood education, play-based learning and science and engineering practices. This pilot study resulted in rich textual descriptions of children's engagement with various practices of science. Still images (digital photographs) were used as additional evidence to support textual descriptions.

The SciEPOP was designed with three distinct observational targets: science and engineering practices, pedagogical strategies, and playspaces and materials. We discuss each target briefly below.

The instrument requires trained observers to identify specific incidents during which children are engaging in one of the eight NGSS-aligned Science and Engineering Practices (Appendix F) (NGSS Lead States, 2013). Included in both the paper and app-based formats of the SciEPOP are brief descriptions and examples of each practice, allowing observers to make evidence-based decisions quickly. Practice 1 (Asking Questions) and Practice 8 (Obtaining, Evaluating, and Communicating Information) were coded separately because researchers were not able to determine *a priori* categories that aligned with the ordered hierarchies established for Practices 2 – 7. One of the guiding principles underlying the NGSS-outline practices is that students will make consistent progress in the complexity and sophistication with which they engage in SEPs; this progression is specified in successive grade bands. Likewise, the SciEPOP was developed with the understanding that children's engagement with SEPs will vary in complexity within and among individuals, sites, and over time. Therefore, the instrument allows observers to note the proficiency with which children engage in such practices, on an ordinal scale from "Emergent" (Level C) to "Proficient" (Level B) to "Exemplary" (Level A). These categorical descriptions, as discussed above, are informed by both pilot study data and prior work related to learning progressions and science practices (e.g., Berland & Reiser, 2008; Duschl & Bybee, 2014; Gotwals & Songer, 2013; Lehrer & Schauble, 2015; Schwarz et al., 2009), as well as the NGSS grade band expectations (Appendix F) (NGSS Lead States, 2013). For each SEPs, Level A engagement is specifically tied to at least one of the NGSS K-2 grade band expectations. Levels B and C may also be tied to NGSS K-2 grade band expectations and outline the progressive developmental steps toward Level A. For an example of how these codes are described and assigned using the SciEPOP, see Table 1 below.

Table 1. Excerpt from SciEPOP practice 2: developing and using models

Practice 2	Level A (Exemplary)	Level B (Proficient)	Level C (Emergent)
Developing and Using Models	• Develop or use a model to predict or explain something about the natural or designed world • Evaluate or revise the model (as when children add new components – branches, bark, roots – to their "castle" or "house" or indicate revisions – e.g. "This gate needs a lock" as they modify it)	• Compare model to the referent in the natural or designed world (identify common features and differences, i.e. correspondences and non-correspondences) • Develop a simple model based on evidence to represent a proposed object or tool (this includes physical models, 2D drawings or representations, and embodied models when children "pretend to be" something)	• Use physical replica as directed (by a teacher – e.g. "flip over your buckets and sit down in your boats"!) or intended (e.g. toy car; puzzles) • Distinguish between a model and the actual object, process, and/or events model represents

Pedagogical strategies - the behaviors of teachers as they interact with children engaging in SEPs - are a second key component of the SciEPOP and this study. The instrument allows observers to note any of seven pedagogical strategies: scaffolding, modeling, asking questions, direct instruction, disruption of play, mediating conflict, and safety concerns. As noted in more detail in our Results section, we grouped these strategies into two groups for analysis: management (actions that hinder play) and facilitation (actions that facilitate play).

Finally, the instrument allows observers to note details about the physical space and environment in which the observation takes place. This includes information about the materials and toys available to children (i.e. shovels, toy cars, water tables, play structures) as well as the "natureness" of the environment (i.e. presence of trees, dirt piles, wildlife, etc) (Sobel, 2015). While these factors are not individually analyzed in the present study, they offer a rich descriptive context for analyzing specific incidents as well as potential for future analyses. In our analysis, we use site profiles as proxies for physical space; each site offers a unique environment, characterized by indoor and outdoor space, access to nature and wildlife, and materials available to children during playtime.

The SciEPOP has two overarching purposes for use in the field. First, the instrument allows researchers to identify and categorize classroom-level engagements with science and engineering practices that support STEM learning. Second, the instrument provides data on "supporting characters" – the physical environment and materials as well as the educators' roles in the space. Together, these data allow researchers to describe and make claims about the integrated relationship among play, STEM, and early childhood environments. Our instrument development study (Saenz & Miller, in process) provides sufficient evidence to suggest that the SciEPOP successfully captures a wide range of levels and experiences across all eight practices, as well as critical information about physical space and pedagogy.

Methodology & Participants

This mixed methods study uses an exploratory sequential design (Creswell et. al., 2003) conducted over one year to account for seasonal changes in children's learning environments. Data were collected at four preschools in the Northeastern United States. The preschools were located in four different towns to capture a variety of demographics among participants including varying levels of rurality, income, and racial diversity. Three sites are Head Start programs, accounting for a range of families' socioeconomic backgrounds; two of those sites are associated with the same national nonprofit organization, another site is associated with a national nonprofit organization established with foundation support, and one site is associated with a liberal arts college, primarily serving families of faculty and staff at that institution (Table 2).

Site A is a nature- and play-based preschool, prioritizing self-directed play and eschewing plastic toys in favor of natural materials, "loose parts" (Nicholson, 1971) and outdoor spaces. Site B is a well-resourced, academic-focused, play-based preschool with ample space and materials for play but with a high degree of structure and teacher-directed activity. Site C is an under-resourced preschool which researchers characterize as "childcare-focused" and traditional in terms of spaces, materials, and schedule. Site D is moderately resourced, traditionally structured, and strikes a balance of childcare-focused and academic-focused. Full site profiles appear in the section below.

Table 2. Participating site demographics

Site	Enrollment	**Low income**	White	African/AfAm	Hispanic/ Latino	East Asian & Pacific Islander	Multiracial
A	46	0.0%	91.3%	0.0%	6.5%	0.0%	2.2%
B	208	76.0%	91.8%	0.0%	0.0%	1.9%	6.3%
C	63	28.6%	81.0%	6.3%	3.2%	3.2%	6.3%
D	60	10.0%	91.7%	0.0%	0.0%	1.7%	6.7%

Note: % of low income students is determined by % of Head Start eligible students.

Researchers did not individually identify participants for this project as the focus was on children's engagement with science and engineering practices during play rather than on individuals. Additionally, enrollment of students at three of the four preschools fluctuated over the course of the school year with some children leaving the schools and others joining preschool classrooms in between the four rounds of data collection. We provide greater context around demographics, teacher credentials, and curricular and pedagogical approaches in the site profiles that follow.

Site A Profile. The Site A preschool is housed in a childcare center associated with a college. The center has capacity for approximately 46 children from infancy through preschool. Of the teachers employed full-time at the center, 56% of them held master's degrees in ECE, including all three preschool teachers. The other 46% held bachelor's degrees. Site A was characterized as both nature-based and play-based with a strong leaning towards an attachment-based theory of care. Drawing from Reggio-Emilia and Waldorf-inspired approaches, the center website offers that "learning occurs when deeply attached relationships with adults and uninterrupted play exist". The preschool environment offers natural materials and "loose parts" (Nicholson, 1971) for children to use in their play. This reflects the philosophy of play that play materials should not dictate play, but rather familiar objects and materials (e.g. stones, fabrics, stumps, pillows, blocks) should be reflective of objects the child encounters in everyday life and should inspire rich and imaginative play (Olsen & Smith, 2017; Sutton, 2011). Further, the outdoor play yard could be characterized as a natural playspace, including stumps, sticks, dirt pathways, sand piles, climbing structures made from natural materials, and ample trees and shrubs to play among. While buckets, shovels, rakes, pans and scoops were readily available to children in the playspace, notably absent were any plastic toys.

Site B profile. The Site B preschool is part of a national nonprofit organization which aims to support young children from disadvantaged communities towards academic, social, and emotional readiness for school. The organization describes the four core features of their model as: data utilization, embedded professional development, high-quality teaching practices and intensive family engagement. The preschool is situated within a program that serves children and their families from infancy through preschool. The total program enrollment was 208, with 115 of those children enrolled in Head Start and 43 in Early Head Start. More than 75% of children at Site B qualify for FRL. Of the full-time lead teachers, 4% held a doctorate, 14% held master's degrees in ECE, 57% held bachelor's degrees, and 3% were enrolled in bachelor's degree programs. The Site B website touts a continuity of care and wrap-around service model, emphasizing "trust and relationship building" as well as "child-directed play". They use a published preschool curriculum which emphasizes literacy and social-emotional development. The preschool classrooms observed were highly structured and academically focused. Classrooms were divided into areas or stations for various types of play and learning. These included areas for blocks, sensory tables, art, reading, and dramatic play.

Children were encouraged to write their names on small whiteboards which hung at each area or station while they were playing there. This appeared to be a way for teachers to manage how many children were in any one area at a time and popular stations (such as the sensory table) often had a waitlist of children's names on the white board. The outdoor playspaces for preschoolers were described as natural playspaces and were divided into two large areas with a fence running in between. The outdoor spaces were constructed with a combination of natural elements (log-edged pathways, berms, shrubs and small trees) and man-made structures like slides, paved walking paths, synthetic turf, playhouses, and swings. Buckets, shovels, balls, and other toys were sometimes made available in the play yard but not always. Classrooms contained a traditional array of dolls, dress up clothes, Legos and other building materials, as well as plastic play food, books, and art supplies.

Site C profile: The Site C preschool is affiliated with a National nonprofit organization committed to "youth development, healthy living, and social responsibility". Site C enrolled a total of 63 children from infancy through preschool. Of those children, more than 50% qualified for FRL and 14% of those children were living in foster care. Of the nine full-time teachers at Site C, 11% held bachelor's degrees, 22% were enrolled in bachelor's degree programs, 22% held associate degrees, 11% were enrolled in associate degree programs, and 33% held no degrees. When asked about the program's theory of care, the director responded that they "create a safe and healthy living space for all children from all walks of life to thrive and grow at their own pace". This aligned with the program website which states that, "Our goal is to provide children with a safe and healthy learning environment that stimulates physical, social, emotional, and intellectual growth". Notably, the language of the program website emphasizes "childcare". This stands in direct contrast with Site A which emphasized language around play and secure, attached relationships and Site B which emphasized language around play and academic "readiness". Site C was located in a large, multiuse building in an urban area. Indoor classroom spaces (one for preschool-aged children and one for pre-K) were divided into areas or stations including blocks, dramatic play, movement, sensory table, reading, and several tables for teacher-led activities. The reading area in the pre-K classroom included a rocking chair and a carpet on which children could sit. The Site C indoor spaces included a traditional array of dolls, blocks, plastic play food, cars, trucks and figurines (e.g. dinosaurs, animals) and a plastic castle climbing structure with slide. Play areas were considerably more cluttered with toys and materials than at any of the other three sites. Children were permitted to use certain areas during free play and were prohibited from other areas by teachers.

The outdoor space at Site C was the smallest and most restricted of the four sites. The play yard was a narrow (approximately 5 meters across), fenced area that ran along the length of the building (approximately 20 meters). The play yard was covered in wood chips and had two climbing structures, one with sliding boards, in the center. At one end of the play yard was a staircase up to the main building where the classrooms were housed and at the other end of the play yard was a small plastic playhouse and a stationary metal rocking play structure shaped like an airplane. During the summer months a small water table was brought outside and sometimes filled.

Site D profile. The Site D program is affiliated with the same national nonprofit organization as Site C, though unlike Site C which is housed in a multiuse building, the Site D program is housed in a stand-alone building dedicated to childcare. The website of Site D articulated the same theory of care, stating "Our goal is to provide children with a safe and healthy learning environment that stimulates physical, social, emotional, and intellectual growth". Of the fourteen full-time teachers at Site D, 14% held bachelor's degrees and 21% were enrolled in bachelor's degree programs, 29% held associate degrees, and 36% held no degrees. The program focus appeared to be a combination of childcare and academic readiness, with more focus on the latter than researchers found at its sister site (Site C). Researchers noted that a significant number of families using that program were professionals employed by an adjacent college or by the hospital just down the street. Classroom spaces in Site D were more similar to those at Site B than at Site C. Rooms were neatly arranged into areas and stations including blocks, sensory tables, reading, dramatic play, and tables for art or other teacher-led activities. A traditional array of toys and materials were neatly arranged on shelving units that also delineated different areas for play and at Site D children were encouraged to take a small, laminated photo of themselves off of the wall and place it on a holder at the station they intended to play at during "free play" time. This appeared to be a way of managing how many children could play in one area or station at a time. Children were frequently reminded that they needed to find another area to play in if they entered an area where the determined limit of children had already been reached.

Site D had a large outdoor playspace with multiple large mature trees providing shade. In the center of the play yard was a very large climbing structure with multiple levels, slides and stairs. There was also a structure that appeared to have once had swings, but those had been removed. Around the playspace were several other structures, some movable (like a small plastic playhouse and picnic table) and some stationary, like a metal rocking structure. Central to the outdoor space was a very large tree along a sloping section of the yard. On the downhill slope, the tree roots were partially exposed, and children were frequently found digging, playing, and just sitting among those roots. For reasons not explained to the researchers, the side of the play yard to the other side of that large tree was off limits for the children and a spool of pink tape had been wrapped around the tree and draped along the yard between the large tree and another smaller tree. Children were reminded to stay on the near side of that tape line if they strayed under it. There were very few toys or materials brought onto the play yard relative to the number of children playing there. There were some trucks and cars as well as occasional tubs, shovels, and buckets. During the summer months researchers observed children playing with tubs of water and paint brushes (brushing water on the brick wall of the building and "washing off" the chalk art they had created there). Additionally, a sprinkler was brought out onto the play yard occasionally on hot summer days. The playspace at Site D was uniquely divided into the area of the large climbing structure, which seemed to host running, climbing, and generally loud, energetic play, and the large tree on the slope of the yard which appeared to attract more quiet play and rest among children.

Data Sources and Analysis

Researchers spent one year observing and recording children engaged in "free play", gathering more than 120 hours of video data across four preschools; at least eight hours of observation occurred at each of the sites during each of four seasons for a total of more than 30 hours of data per site over the year. Data were collected at four different times over the course of one year to account for seasonal changes in the play environment. Data were subsequently coded and analyzed using NVivo software. Data collected in this study suggest that the SciEPOP instrument allows trained observers to accurately and reliably capture and discriminate among all eight of the SEPs identified in the NGSS, as well as capture critical information about physical space, materials, and pedagogy.

Video data were then analyzed in NVivo using an *a priori* coding scheme developed to align with the SciEPOP. Coding was done at the grain size of complete instances or vignettes where students engaged with one or more practices during play. For each of these engagements the video was coded for each practice at Level A (Exemplary), B (Proficient), C (Emergent), or D (Not Present) along with notes related to "physical space" and "pedagogy".

A Note on Site Selection and Comparisons

Given that "playspace" is a key variable in our research questions and analysis, it is important to articulate how it is operationalized in this study. Selection of the four sites profiled above was an intentional decision and significant for the results and discussion that follow. Learning environments are complex systems in which children's development is shaped by the intertwining of their prior knowledge and background, relationships with peers and adults, interests, physical space, available materials, and more. There exist as many *types* of learning environments as there are sites, though some sites share significantly more elements in common. We use individual site contexts as proxies for playspaces, necessitating a rich description of each site and a nuanced examination of how each site's environmental context may reveal important underlying patterns related to space and pedagogy.

Some patterns in our analysis of science and engineering practices across the four sites (for example, the finding of higher frequencies of Level A practices at Site A, which serves a population of children of parents with typically high levels of educational attainment) might be dismissed by attributing them to selection bias. However, in order to make this argument, one must assert that some children are more capable of engaging in scientific inquiry than others, and that this proclivity is explained entirely by one's family background and not by the learning environment or by the pedagogy teachers engage with when interacting with students. We believe that this interpretation is short-sighted and runs counter to the pursuit of establishing more equitable learning environments for all children. We have intentionally selected sites for research that exhibit overlaps as well as differences. For example, both Site A and Site D serve families that work at colleges or other professional institutions. Sites B and D share similar physical spaces and materials inside and outside of the classroom. Finally, Sites A and B are similarly well-resourced and staffed with qualified EC educators, though the populations they serve are quite different. We have attempted to contextualize the four sites so that the emergent patterns around children's engagement with science and engineering practices in play, and the pedagogical supports that support or inhibit those engagements take on the significance they deserve.

Results

In this section, we present the results of our multi-stage analysis, beginning with overall patterns of children's engagement with science and engineering practices. We then break these patterns down by site and by practice level. In the second stage, we present findings specific to teacher pedagogy, overall and specific to site and level.

Science and Engineering Practices in Play

Our observations captured all eight practices at our four sites, though these practices were not evenly distributed. Practices 1, 2, and 3 were most frequent (4.8, 5.4, and 4.2 codes per hour, respectively). Practice 4 was observed 2.2 times per hour, and Practice 6 was observed 1.2 times per hour; Practices 5, 7, and 8 were the least frequently observed, each under one time per hour. Figure 1 below shows these frequencies.

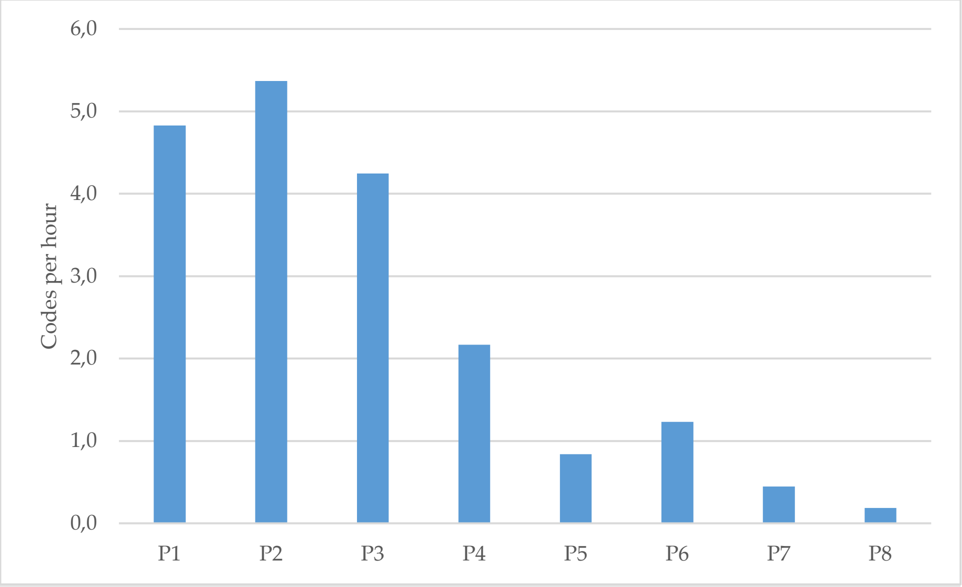

Figure 1. Practice frequencies (all sites)

It is clear that preschool-age children are frequently engaging in science and engineering practices while at play. They engage most frequently in asking questions (P1), developing and using models (P2), and planning and carrying out investigations. This is true across all four sites in our study, despite the significant environmental, pedagogical, and demographic differences among these sites. These frequencies are not particularly surprising to anyone who has worked with or raised children, since much of play involves investigating one's surroundings, asking questions that arise in those investigations, and because pretend play requires the ability to transform objects and actions, assigning them with symbolic meaning (Bergen, 2002), a skill directly related to modeling practice. For instance, we observed numerous examples of children playing with toy cars or trucks and speaking about them as "toys". These instances were coded as P2c because children demonstrated that they could "distinguish between a model and the actual object, process, and/or events model represents" (Table 1). However, in some instances children transform those toy replicas through pretend play as when one child lifted a toy truck off of the ground and began "flying it" through the air while making noises associated with a rocket or an airplane. This instance was coded as P2b because the child was using the object at hand (a toy truck) to represent something else (an airplane).

When we examine the distribution of SEPs by site (Figure 2), we find that overall, the total number of practices observed at each site does not vary significantly; sites range from 20.1 practices (Site B) to 26 practices (Site D) per hour.

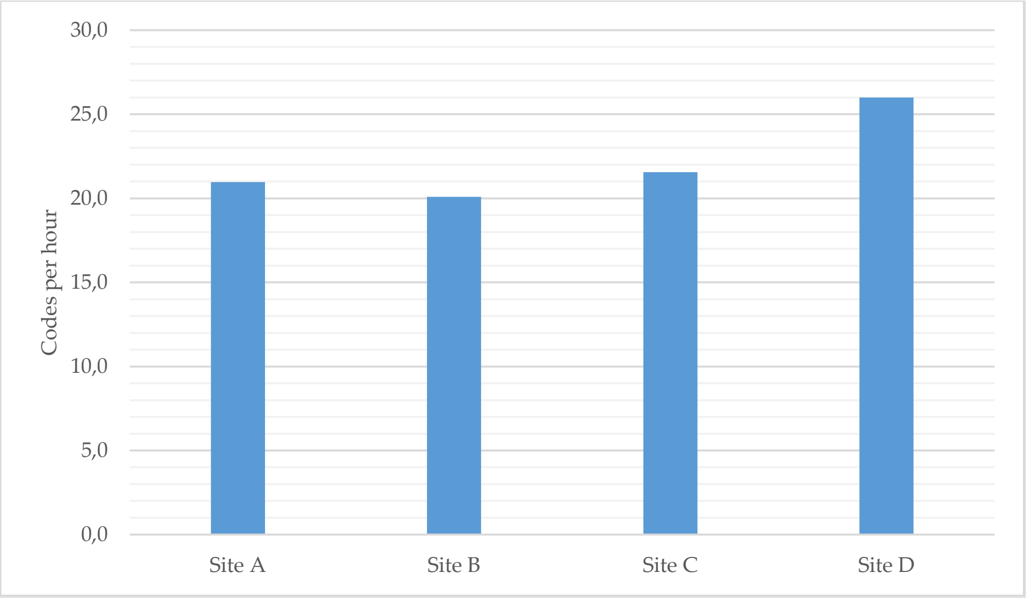

Figure 2. Total number of practices by site

Similarly, we captured SEPs at all proficiency levels – Emergent (C), Proficient (B), and Exemplary (A) in our observations. As seen in Figure 3 below, the differences across levels are large; frequency of practices is lowest at level A (0.74 codes per hour) and highest at level C (17.68 codes per hour). This is expected, as the practices and our corresponding levels are benchmarked to the K-2 NGSS standards, and our sample is younger and more likely to be at the earliest stages of these emerging practices.

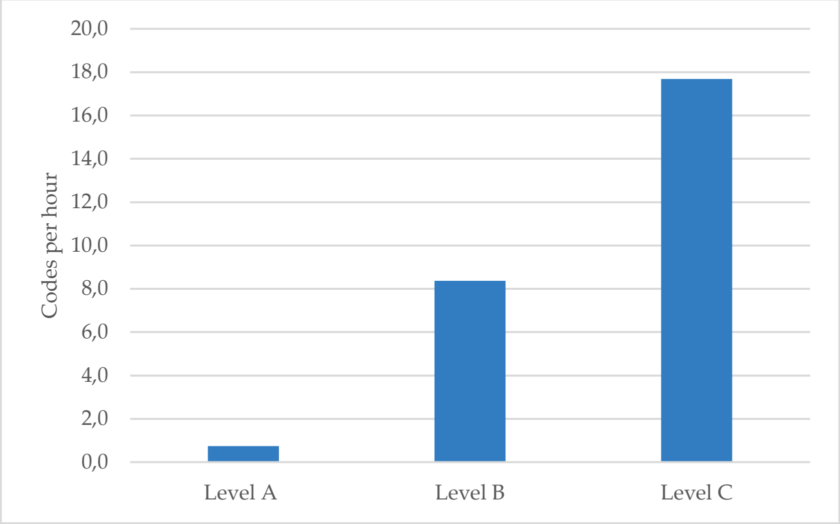

Figure 3. Level frequencies all sites

If we break these patterns down further, we see some site-based patterns emerge (Figure 4). Level A practices are observed much more often at Site A (1.85 codes per hour), fewer than half as much at Site B (0.69 codes per hour), and almost never at Site C or D. Conversely, Level C practices are observed most frequently at Site C (18.39 codes per hour) and Site D (19.67 codes per hour). Our transcripts also reveal that engagements in practice at level C are often fleeting, in situations where children begin to explore or engage in a particular way but then get distracted or disrupted and move to something else. These vignettes tend to be shorter than instances where children are more deeply engaged in play-based exploration or problem-solving and so it stands to reason that observers would see higher frequency counts of these more nascent practices (which are often incomplete engagements).

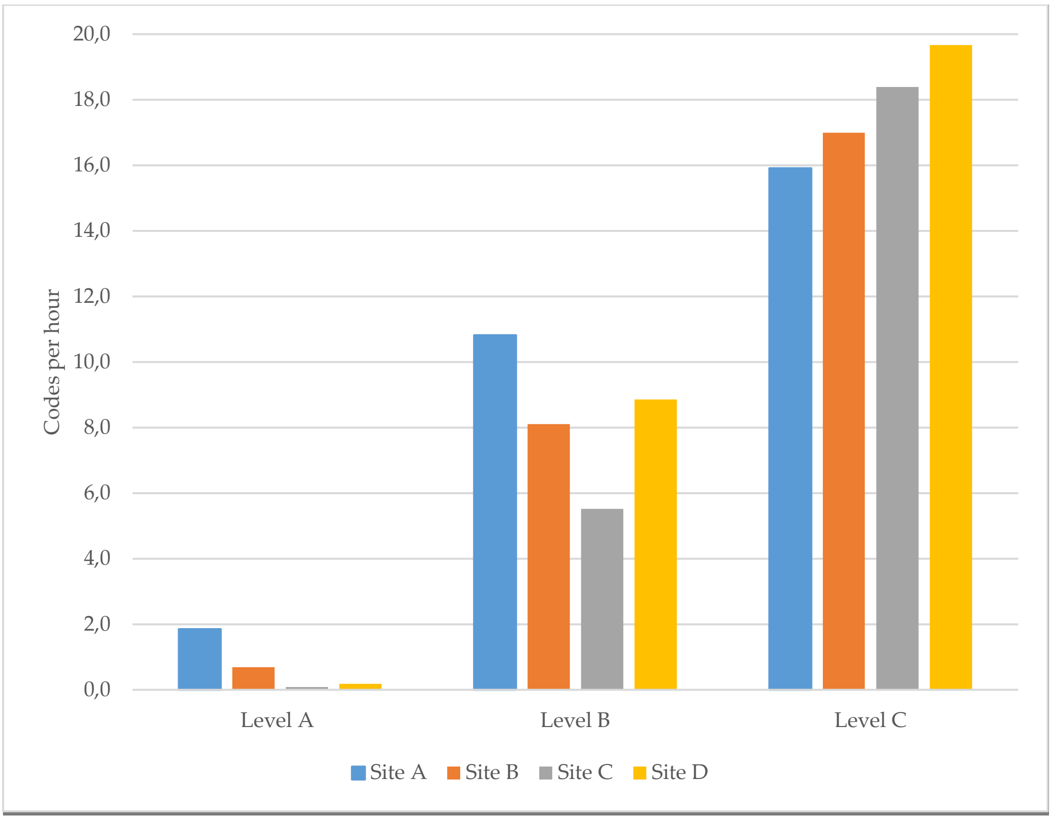

Figure 4. Level frequencies by site

For example, we documented more than 340 instances of P4c; this emergent level of analyzing and interpreting data includes instances where children collect and/or record data (including observations or measurements), recall previously collected data, or recognize patterns in the world. Frequently, P4c codes were used to capture children making single observations; these ranged from noticing changes in weather (e.g., "It's raining"; "This sand is all wet") to observing what happened when a teacher tipped a jar of applesauce upside down and began tapping it to refill a bowl (i.e., "Some applesauce just came out!"). These engagements were often fleeting. For an instance to be coded at P4b children must "create or describe patterns or relationships in the natural or designed world" (Appendix F) (NGSS Lead States, 2013). In other words, children must use multiple data points in order to interpret something they measure or observe. The conversation that follows was recorded at Site D during snack time:

> [children sitting around a table having snacks]
> Student 1: [looking towards a window] Why is the world...why is the world.... Why is the world going up?
> Teacher: Why is what going up? [child points toward the window, T turns around and looks] Why is the world going up? Do you mean the Sun?
> Student 1: [nods, mutters inaudibly]
> Teacher: The Sun goes up. That's what it does. It rises... in the morning.
> Student 2: The Sun goes up...
> Student 3: And when does the Moon go up?
> Teacher: When does the Moon go up?

[multiple students talk at same time]
Student 3: It goes up at night time!
Student 4: And then the Moon goes up, and then it's bedtime! And then we go to bed and go to sleep.
Student 1: The Sun goes down and the Moon comes up and then it's time for bedtime.
Student 2: Yeah. When the Sun comes up, it's not bedtime.

In this instance, Student 1 looks through the classroom window and makes an observation about the sun rising. This is followed by children making sense of what they know about Sunrise and Moonrise: that one is associated with morning, and one is associated with night or "bedtime". These observations are pulled from both the present (Student 1 observing the Sun outside) and from recalled observational data (children indicate familiarity with day and night cycles).

Our final illustrative example is of P4a; Benchmarks for P4a on the SciEPOP include "Analyze data to determine if a tool, object, or process 'works'" and "Analyze data to answer scientific questions and solve problems". In the example that follows (Figure 5), students make observations about a pretend birthday cake (P2b) and figure out how many (stick) candles they need before critiquing and revising their model (P2a) to account for their interpretation of the observational data (about the weight of mud versus dirt on top of the 'cake'):

Student 2: Can I have another candle? Because someone is going to be ten.
Student 3: I need ten candles. So I need six more, I think.
Student 4: So you have, [pointing as she counts] 1, 2, 3, 4, 5...
Student 3: I have seven.
Student 4: So you need three more.
Student 3: Here are your three more so you have ten!
Student 5: We have ten candles in ours!
Student 2: I'm going to light mine
Student 1: Do you want to do mud on top of them? [drizzles mud on top of one stick] Oh no!
Student 2: What!?
Student 1: It's falling over! I have some more mud...
Student 4: The MUD makes it heavier, so it tipped over.
Student 3: Yeah. We don't have mud, so it stays.
Student 1: [to Student 2] Do you want to do dirt like them?
Student 2: Yeah. Yes.
Student 1: Let's do dirt like them. [Student 2 begins to sprinkle dirt on top]
Student 4: We're not putting dirt on top of them [sticks/candles]
Student 2: On top of the cake! [continues to sprinkle dirt]

Figure 5. Children use mathematics and make observations about the "candles" in their "cakes"

Engagement with Practice 4 may happen in a matter of seconds, as with a single observation about the weather or may be sustained over several minutes or longer as children engaged deeply in observation, analysis, and interpretation of the data at hand.

Teacher Pedagogy in Play

When teachers engage with children at play, they are necessarily influencing children's behavior and thinking, even when that influence is not apparent. Some types of pedagogical practices are more influential than others; for example, a teacher who notices a child experimenting with using a stick as a lever might say, "Be careful!" This interjection might result in the child pausing, or reconsidering their actions, but is unlikely to push the child into further investigation. However, a teacher that intervenes to say, "What do you notice when you use that stick to lift heavy rocks?" is likely prompting children to explore the science and engineering elements of their play.

Teacher behavior, like student learning, is multifaceted and difficult to predict. Some behavior, however, is shaped by the site itself; preschools develop and train their employees to enact a particular set of norms and values in their work. When these sites differ in the ways they prepare teachers, we expect to see differences in the types and frequencies of teachers' engagement with students at play. Our analysis bears this out. Figure 6 below shows the distribution of total pedagogy codes by site.

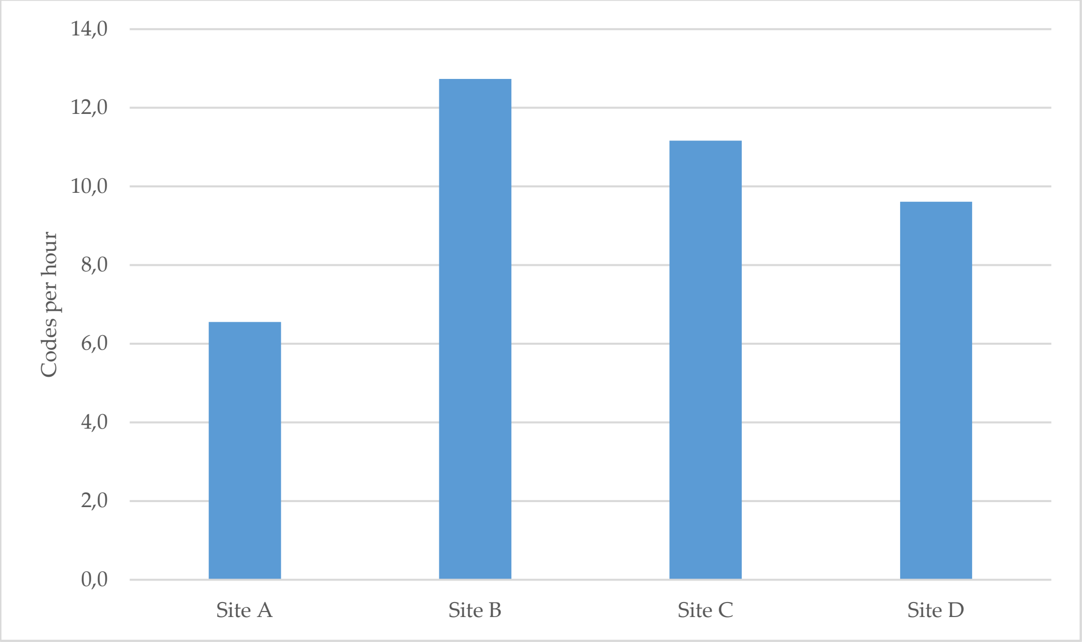

Figure 6. Total pedagogy codes by site

As seen clearly in Figure 6, teacher intervention during children's play happens least frequently at Site A (6.56 codes per hour), and most frequently at Site B (12.73 codes per hour). This difference between Site A and B is important, because both sites purport to have similar approaches to space and play.

When we look at the breakdown of individual pedagogy codes in Figure 7, another clear pattern that emerges is the relative low frequency across all teacher pedagogy codes at Site A compared to other sites.

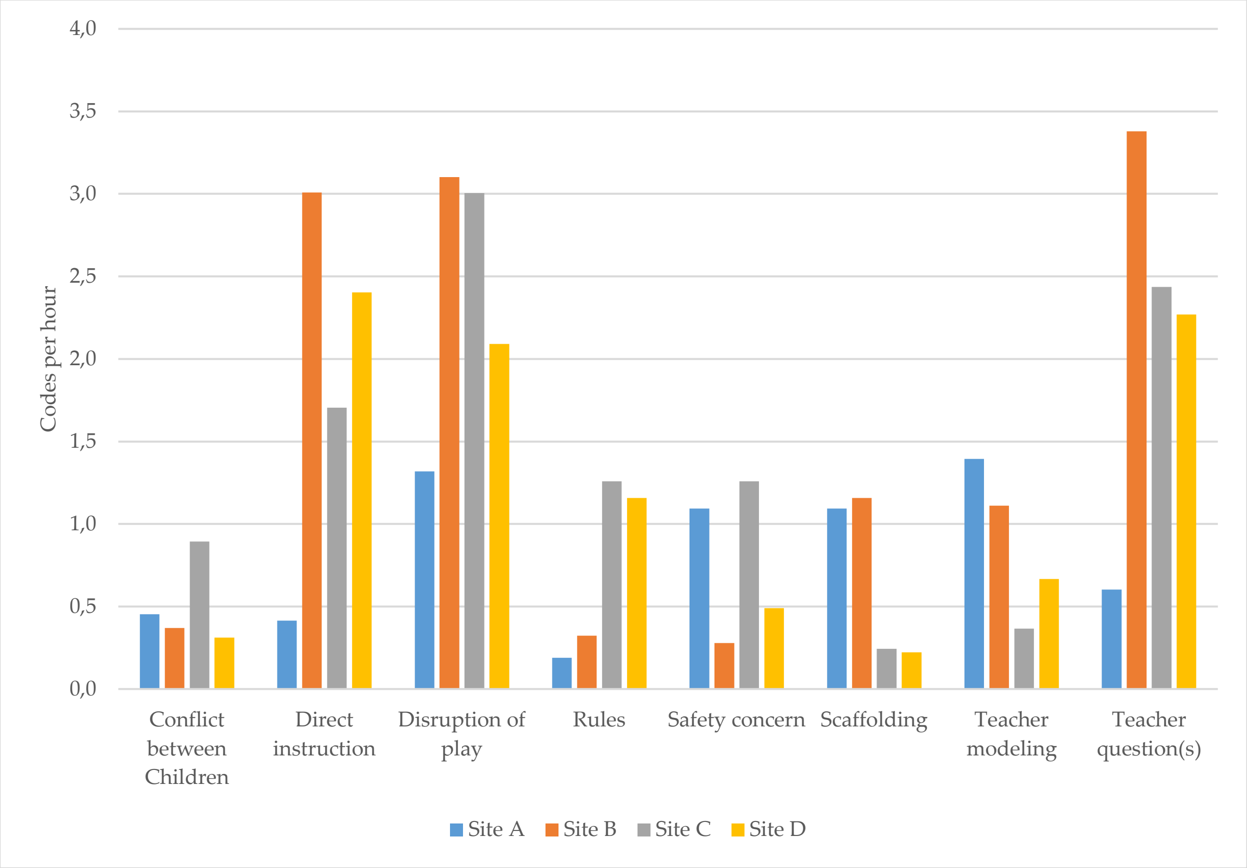

Figure 7. Individual pedagogy codes by site

This is especially true among the codes for direct instruction, disruption of play, rules, and teacher questions. Site B, on the other hand, exhibited the highest frequency of interactions for direct instruction, disruption of play, and teacher questions. The stark differences in teacher pedagogy between Sites A and B is revealing, as while both sites describe their approach as "play-based," Site A is centered around close teacher-student relationships and "uninterrupted play". At Site A instances of direct instruction were infrequent, with teachers more often modeling particular behaviors (e.g., digging or stacking loose parts) or quietly scaffolding children's play (e.g., placing additional tools or materials near a group of children engaged in exploratory play). By contrast, Site B emphasizes academic and social school readiness and touts "data utilization" as a "core feature" of their model. It is not surprising then that we saw the highest frequencies of direct instruction and teacher questions codes at Site B. The significantly higher rates of "rules" interventions by teachers at Sites C and D is reflective of their emphasis on childcare and behavior management.

To get a better understanding of how teachers' patterns of interaction varied by site, we grouped pedagogy codes into two categories: management codes and play facilitation codes. These categories reflect an important conceptual difference in our analysis between actions that *support* science-engaged play and actions that *hinder* science-engaged play. Management codes include: safety concern, disruption of play, rules, and conflict among children. Play facilitation codes include: direct instruction, scaffolding, and teacher modeling. Teacher questions were analyzed as a separate category, as we expect in future analyses to find that these questions differ by type. Figure 8 shows the patterns of these categories across sites.

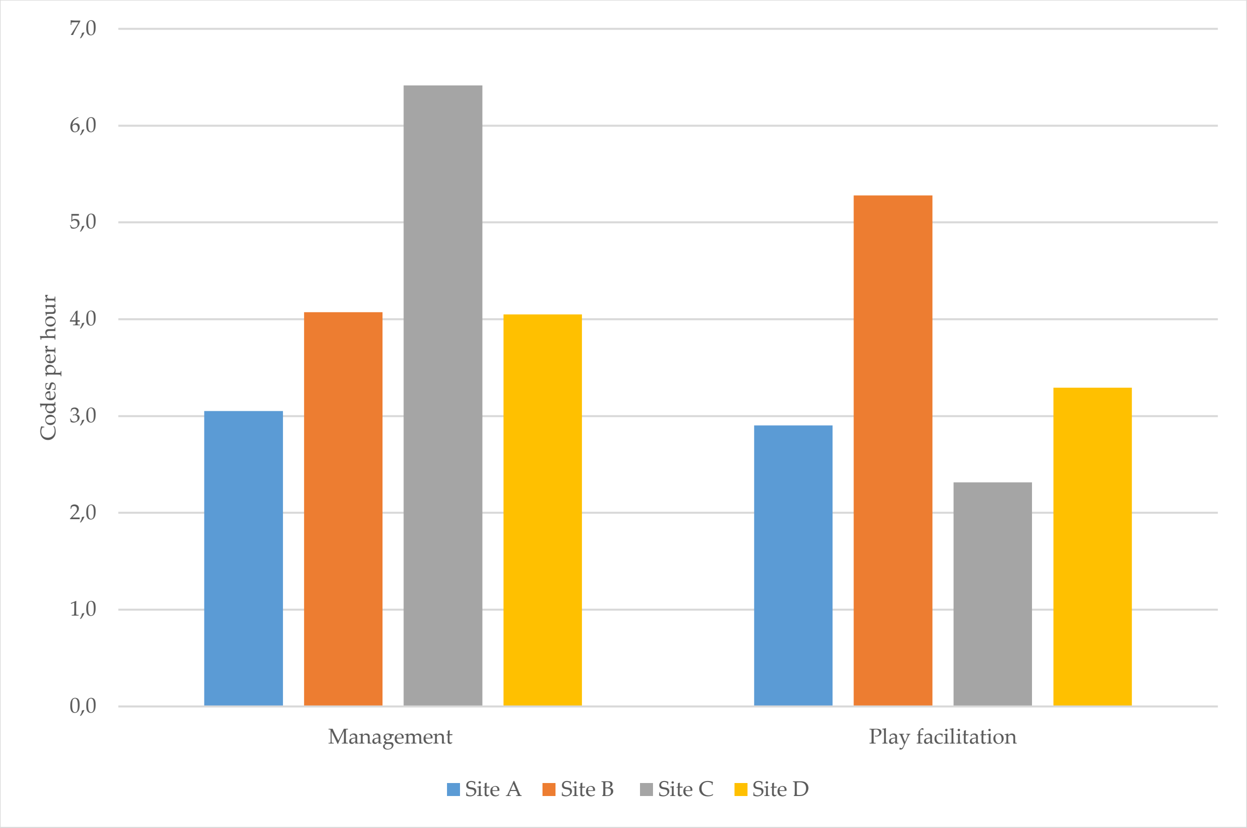

Figure 8. Pedagogy categories by site

When teacher interventions are grouped into "management" and "learning support, clear differences emerge across the four sites. Teachers at Site C engaged in management pedagogies more frequently than other sites, and engaged in play facilitation pedagogies least often. At Site B, teachers engaged in play facilitation pedagogies most often. Overall, teachers at Site A engaged in management and play facilitation at similar frequencies.

Relationship between Pedagogy and SEPs

Our analysis in this section focuses on the relationship between pedagogy and SEPs. Figure 7 shows the distributions of intersecting pedagogy codes at each practice level. The patterns of intersection are similar across all three practice levels; "disruption of play" and "direct instruction" are the two most commonly occurring and overlapping codes at each level. For example, at Level A, the most frequent intersections are with "disruption of play" (4.65 intersections per hour) and "direct instruction" (3.4 intersections per hour).

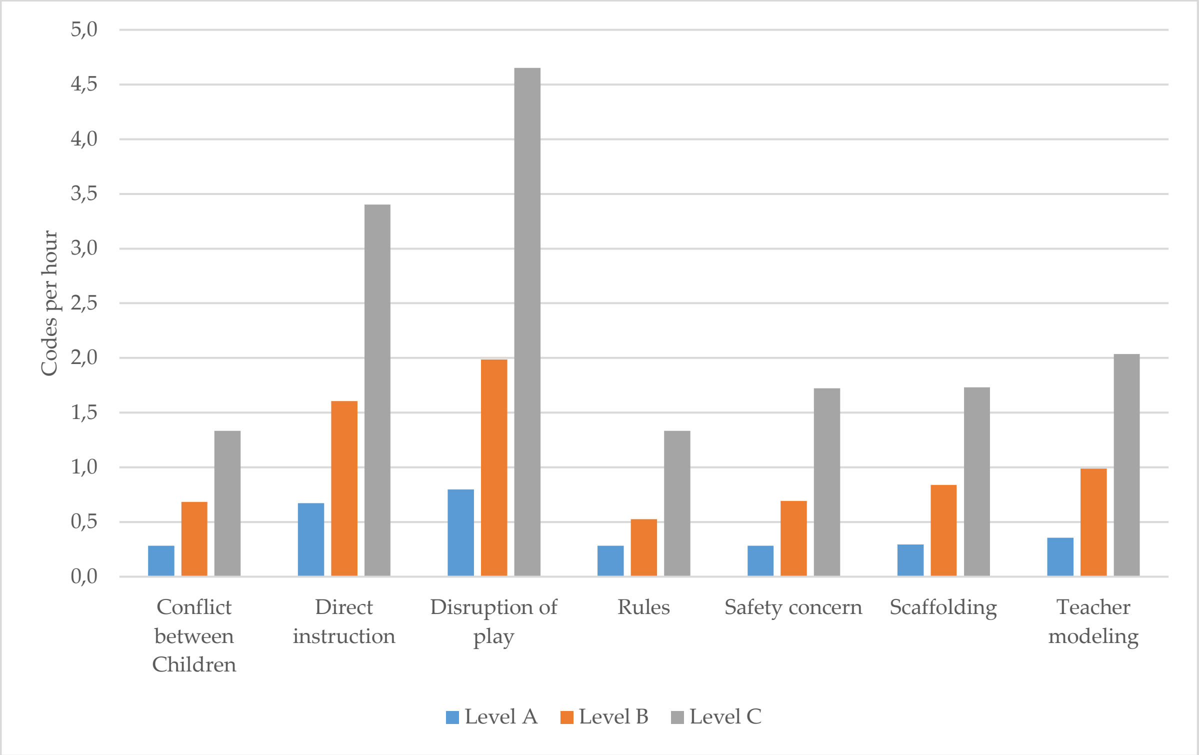

Figure 9. All pedagogy codes by practice level

These pedagogical practices share an important feature – a teacher interrupting to place themselves at the center of children's play. Though direct instruction may offer a chance for children to receive relevant, science-specific information, it also risks interrupting the play that allows for creative self-guided exploration of science and engineering. This approach is in specific contrast with Site A, which promotes "uninterrupted play" as key to children's learning, and where we observed the lowest rates of disruption *and* the highest rates of Level A practices.

Contextualizing the Relationship between Teacher Pedagogy and Students' Science Practices

In the section that follows, we will provide greater context for the relationships we see in the data between teacher's pedagogy and children's engagement with play-based SEPs. We will present excerpts from video transcripts, noting where children are engaging with nascent SEPs. Further, we will present analysis of teacher pedagogy related to these instances.

Nature-Based Water Play with Teacher Scaffolding

In the transcript excerpts that follow, children are playing in water flowing from a hose down an embankment and into the gully that runs under a footbridge on the play yard. Two children begin this investigation around flowing water as a teacher observes from the footbridge above. They are quickly joined by other curious preschoolers and the purpose of their play shifts from investigation of water flow (science) in Figure 11 to problem solving with the children removing obstacles to make the water flow under the bridge(engineering) in Figure 12 (Cunningham, 2017; Cunningham & Carlsen, 2014).

Figure 10. Children observe flowing water from a hose

1 Student 1: Give me more dirt
2 Student 2: Why?
3 Teacher: [explains to another child] He's asking [child name] for more dirt so he can block the hole.
4 You could ask him, "why do you want to block the hole"?
5 Student 3: [repeating] Why do you want to block the hole?
6 Student 1: So it [water] doesn't go that way.
7 Student 2: And I'm still working on that rock [inaudible]...
8 Teacher: You're still working on how to get that rock out of the ground.
9 Student 2: Oh look! It's drying all up!
10 Teacher: Well, why do you think it's drying all up?
11 Student 2: Oh, wait! The dirt is pushing it now. If the dirt pushes it, it will go more backwards.
12 Student 1: Wait. Here it comes faster 'cause I took some dirt out of the way.
13 Student 2: Yes. Now let's try and move this rock. We need more muscles.
14 Student 1: That means [child name] has to help again.
15 Student 4: I can help...[inaudible]

In the beginning of this excerpt, the children are negotiating their purpose (P3: Planning and Carrying Out an Investigation). One child is already manipulating the flow of water down the embankment by moving and shaping the dirt in its path. After asking a questions (lines 2 and 5) to clarify what Student 1 is doing, Students 2 and 3 join him in an attempt to clear weeds and rocks from the water's path. Both Students 1 and 2 make observations about the flow of water (lines 9, 11, and 12), and the teacher observes from above, modeling questions for the children like, "You could ask him, 'why do you want to block the hole?'". The children use observational data to inform what they do next as their teacher models the types of questions they might ask (lines 3-4) and scaffolds their investigation with well-placed questions (e.g., "Well, why do you think it's drying all up?").

Figure 11. Children alter the flow of the water by removing obstacles

16 Teacher: Another set of hands is coming. He's trying to pull that weed. Can you help him pull that weed? 17 How did it get there?
18 [Student 4 and Student 2 both pull at the weed, S4 rips a large part of the week up]
19 Student 2: Super strong muscles!
20 Teacher: There! You got part of it. You DO have muscles. Right at the root; you got it!
21 Student 4: Why is it so...[inaudible]?
22 Teacher: Uh oh, I think they need more help. They need two more hands. Who's hands can help them pull 23 that? Do you have two more strong hands?
24 S: Maybe we need SEVEN hands
25 [Three children now working on pulling the weed by the rock they were trying to move]
26 Teacher: Pull [child name] pull! Do you hear it cracking? Listen when you do it.
27 Student 1: Now we need EIGHT HANDS!
28 Student: I heard it!
29 Teacher: Oh! Are you going to help? Perfect! I'll bet you [child name] can help.
30 Student 2: Eight hands! Eight hands! [three children are pulling at this point]
31 Student 1: Put two more hands on and we'll have eight hands!
32 [four children are pulling - one child appears to be pulling in the opposite direction]
33 Student 1: No! Not that way. This way!
34 Student 5: It's not coming! [All children take turns tugging] It's stuck
35 Student 3: Here comes more water because I'm digging it! [scooping water and dirt along the path of the
36 water] I'm getting more dirt out.
37 Teacher: You know what, [child name]? It looks like you are really determined to get that. Uh! Part of it.
38 You gotta go right to the root. You remember where the roots are? Right at the very bottom?
39 Student 5: It's stuck! Its stuck!
40 Student 1: Woah! Here it [water] comes faster! It's coming faster, guys!
41 [Student 3 tugs and stumbles backward as he pulls the weed from the ground]
42 Teacher: Woah! He did it! Nice job, [child name]!
43 Student 4: How did he do that?
44 Teacher: Well I think you guys loosened it and he came right in and pulled it out.
45 Student 3: I'm strong.
46 Student 2: What!? You're strong [child name].
47 Student 1: Well, he's not very stronger than us. You're not stronger than us, [child name].

In the second part of this vignette the teacher continues to ask probing questions (e.g., "How did it get there?"; "You remember where the roots are?") and to scaffold their investigation and problem solving (e.g., "They need two more hands. Who's hands can help them pull that?"). Meanwhile, the children continue their efforts to remove weeds and rocks such that they can direct the path of the water until it flows under the bridge. In this effort they determine they need ever more strength to pull stubborn weeds and heavy rocks. They use math (P5) as they articulate "how many hands" it will take to pull out a particularly stubborn weed (lines 24, 27, 30-31). "Eight hands! Eight hands!, one student exclaims. A second student notes that at that time there are three children are pulling (3 x 2 = 6) and says, "Put two more hands on and we'll have eight hands!". During this time, the teacher continues to narrate what is happening (e.g., "Another set of hands is coming. He's trying to pull that weed".) and asking questions like, "Can you help him pull that weed?". The teacher alternates between observing and asking questions to scaffold the children's investigation. She also encourages the children saying things like, "It looks like you are really determined to get that". Finally, in Figure 12, the children notice that their efforts succeed as the water begins to flow faster (lines 33-36; 41).

Figure 12. Children investigating under a bridge

48 [Children pull another weed and then are able to roll the rock away]
49 Student 2: We really did need to move that weed.
50 Student 1: Who can help me move the dirt? Who can help me move the dirt?
51 Student 2: Thanks for team-working! You really do have strong muscles, [child name]
52 Teacher: Didn't we say something about teamwork works amazing? That was proof of that, wasn't it?
53 Student 2: Yeah. And me and [child name] and [child name] all helped, and we loosened it for [child 54 name]. We loosened it.
55 Teacher: What did you get the spoon for, [child name]? What are you going to do with it?
56 Student 1: To dig the roots! [Teacher name], I'm going to see if the water is coming under the bridge!
57 Teacher: Is it coming under yet?
58 Student 1: Oh! It's coming under guys!
59 Student 2: It is! [Runs up and over to other side of the bridge]
60 Student 3: It's coming under the bridge!
61 Student 1: It's coming under the bridge, guys!
62 Student 2: Oh, yes it is! [child name], look under the bridge. That's cool! We really did do it!

After making additional (P4) observations (e.g., "we really did need to move that weed") the children finally achieve their goal, as multiple children notice that "It's [water] coming under the bridge"! Over this extended play–based engagement, the group of children engaged with five SEPs, persisting until they achieved their goal, to engineer the embankment such that they could control the flow of water from the hose to run under the footbridge. In all of this, the teacher stood as a careful observer, narrating the scene, asking questions, and encouraging children without ever involving herself directly in their play or disrupting their play.

Discussion & Implications

Our findings reveal that preschool-aged children are engaging in SEPs at play frequently and at emerging, proficient, and exemplary levels. We have captured the breadth (practices) and depth (levels) of children's engagement with SEPs, as well as the pedagogical moves that teachers make when children are playing. We see notable differences in these areas across our four sites, which we argue can, in part, be explained by their specific approaches to play and learning. Site A, which emphasizes secure, attached relationships, and specifically *uninterrupted* nature-based play, is the site where we see both the lowest frequency of teacher interventions during children's engagement with SEPs, and the greatest frequency of

Level A practices. This juxtaposition of fewer teacher interactions with more sophisticated (Level A) enactments of SEPs may initially seem counterintuitive, but considering that deeper engagement with play requires longer periods of undisrupted time, these patterns make sense. Conversely, when we look at Site C, there are a significant number of Level C (Emergent) practice codes, but Site C has the fewest number of Level B practices and virtually no Level A practices. However, when we aggregated teacher pedagogy codes into groups related to "Facilitation of play" and "Management", Site C had the greatest number of "Management" codes across all four sites. This may indicate that children are engaging with SEPs at a superficial level but that they face frequent disruptions to their play and are, therefore, less likely to move into the more deeply engaged play that appears to foster higher-level engagement with SEPs.

While there is ample research to suggest that play should be central to early childhood science learning (Akman & Özgül, 2015; Bergen, 2009; Bulunuz, 2013; Cook et al., 2011; Larimore, 2020), there is wide variation in how play is defined, managed, and supported across EC programs. All four preschools in this study described their programs as "play-based" yet we have identified notable differences in the spaces, materials, and pedagogies children encounter across those four participating preschools. These differences suggest significant gaps in children's opportunities to engage in and deepen their enactment of SEPs while exploring the world around them, and raise questions about equity in early science learning environments that have implications both nationally and internationally for science education practice, research, and policy.

Conclusion

Play is an essential component of children's early learning; however, in order for children to learn and develop through play, they must have access to the time, space, materials, and pedagogy that support it. Preschool settings offer these possibilities, though not all settings emphasize play equally – a fact we observed in our research sites. Scholars have echoed the call from the United Nations (1989) to frame play as a right and not a privilege (Ladson-Billings 2006, 2011; Souto-Manning, 2017). Souto-Manning (2017) posits that in low-income preschools there is a heavy focus on behavioral management and standardization whereas in more affluent preschools, there is much more unfettered, self-directed, "free-play". She links free play to children's agency, arguing that, "In play, children are agents. They are doers... If we are to unleash children's infinite potential, not only do we have a responsibility to position play as a right, we must also understand the agency children need to have during play" (p.786).

Further research is needed to determine how and to what extent the complex interactions among access to play, space and materials, and pedagogical strategies shape children's engagement with SEPs. The patterns we have identified in this paper suggest that each plays an important role; teasing out these roles will provide valuable insight into how ECE programs and teachers can support deep, meaningful science learning without sacrificing play. Time may also play an important role in supporting more sophisticated engagement with SEPs in play; we have noted, anecdotally, instances in which extended play-based scenarios offer greater opportunities for progression along practice levels. Future research may explore this relationship in more detail. Finally, we see great opportunity for early childhood teachers and administrators to use the SciEPOP as both a training and instructional tool. We believe that teachers and school staff can be trained to use the SciEPOP to learn how to identify and support children's emerging engagements with science and engineering practices, specifically at play.

We assert that by increasing and supporting opportunities for deep, engaged play, teachers are necessarily creating opportunities for children to engage in SEPs. This means, quite often, that the best way for teachers to support science learning among preschool children is to stand back – or, at most, to intervene only in ways that facilitate play. These types of pedagogical skills take practice to hone, but they can be supported by both institutional guidelines and professional development. The evidence offered in this paper suggests that teacher professional development is a powerful tool to help mitigate notoriously low science self-efficacy among early childhood educators (Barenthien et al., 2018; Gerde et al., 2018; Greenfield et al., 2009; Saçkes, 2014) and increase children's opportunities to learn science through play.

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Appendix A: Presep Instrument: Observing Preschool Science & Engineering Practices in Play

Practice Code	Time	Level A | B | C	Pedagogy Codes DP | DI | C | SC | S | TM | TQ	P1: Questions IS | B	P8: Information V | W | O	Physical Space	Incident Notes
P2: Developing & Using Models							
P3: Planning & Carrying Out Investigations							
P4: Analyzing & Interpreting Data							
P5: Using Mathematics & Computational Thinking							
P6: Constructing Explanations & Designing Solutions							
P7: Engaging in Argument from Evidence							
Incidental Questions (running tally)							
Observer Notes							

Time

Mark the beginning and ending time of each incident.

Practice Levels

A	Exemplary
B	Proficient
C	Emergent

Pedagogy Codes

DP	Disruption of play
DI	Direct instruction
C	Conflict between children
SC	Safety concerns
S	Scaffolding
TM	Teacher modeling
TQ	Teacher questions

P1 and P8: Questions and Information

For P1, code the types of questions asked during incidents. For P8, code the specific ways students share or receive scientific information.

P1: Questions		**P8: Information**	
IS	Information seeking	**V**	Visual
B	Building	**W**	Written
		O	Oral

Physical Space

Describe key characteristics of the physical environment in which the incident takes place; note the physical space (i.e. outdoor playspace; classroom playspace) as well as key materials present (i.e. shovels & buckets; play structure)

Incident Notes

Note key details about the incident not captured otherwise by the instrument (i.e. topic of investigation, number of children present).

Incidental Questions

Mark a running tally of observed questions that are not captured in a coded incident.

Observer Notes

Note key details about the observation not otherwise captured by the instrument (i.e. total time of observation, time of day/season/weather, other adults present, important contextual factors).

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Research Article

“How will you construct a pathway system?”: Microanalysis of teacher-child scientific conversations

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Abstract: During the preschool years, children’s question-explanation exchanges with teachers serve as a powerful mechanism for their early STEM knowledge acquisition. Utilizing naturalistic longitudinal classroom data, we examined how such conversations in an inquiry-based preschool classroom change during an extended scientific inquiry unit. We were particularly interested in information-seeking questions (causal, e.g. “How will you construct a pathway?”; fact-based, e.g., “Where’s the marble?”). Videos (n = 18; 14 hours) were collected during a three-week inquiry unit on forces and motion and transcribed in CLAN-CHILDES software at the utterance level. Utterances were coded for *delivery* (question vs. statement) and *content* (e.g., fact-based, causal). Although teachers ask more questions than children, we found a significant increase in information-seeking questions during Weeks 2 and 3. We explored the *content* of information-seeking questions and found that the majority of these questions were asked by teachers, and focused on facts. However, the timing of fact-based and causal questions varied. Whereas more causal questions occurred in earlier weeks, more fact-based questions were asked towards the end of the inquiry. These findings provide insight into how children’s and teacher’s questions develop during an inquiry, informing our understanding of early science learning. Even in an inquiry-learning environment, teachers guide interactions, asking questions to support children’s learning. Children’s information-seeking questions increase during certain weeks, suggesting that providing opportunities to ask questions may allow children to be more active in constructing knowledge. Such findings are important for considering how science questions are naturally embedded in an inquiry-based learning classroom.

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Introduction

> *The important thing is to never stop questioning.”* – Albert Einstein

From an early age, children construct scientific knowledge through making observations, carrying out investigations, and exploring the world around them. For example, a preschooler experimenting with toys and food in a booster seat might wonder, “why do some objects fall faster than others to the ground?” Additionally, a preschooler playing with blocks, ramps, and pathways might wonder, “why do some objects travel farther down the pathway?” Through asking questions and manipulating materials in their environment, preschoolers begin to develop a basic understanding of scientific concepts and causal mechanisms, which they continue to shape and refine during formal schooling (Bonawitz et al., 2011; Legare et al., 2010; Legare & Lombrozo 2014).

Although children can acquire scientific information through first-hand exploration, children’s social contexts, including their formal learning environments at school, impact their early learning, interest,

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and engagement in STEM (science, technology, engineering mathematics) activities. In 2019, Congress passed the *Building Blocks of STEM Act*, which explicitly encourages research aimed at enhancing preschool and elementary STEM education, with a focus on the role of teachers and parents. In daily activities such as bookreading and scientific conversations, children often learn through question-explanation exchanges with adults (e.g., Butler et al., 2020; Harris et al., 2018; Kurkul & Corriveau, 2018; Ronfard et al., 2018). Although preschoolers increasingly ask about 76 information-seeking questions per hour (Chouinard, 2007), when children enter K-12 schooling, the number of questions they ask significantly declines, indicating that the preschool years may be critical for optimizing question-explanation exchanges in science learning (Engel, 2011; Tizard & Hughes, 1984).

Yet, little research has investigated how child-teacher scientific question-explanation exchanges shape preschoolers' STEM learning prior to formal schooling (e.g., Skalstad & Munkebye, 2021). Therefore, through naturalistic classroom data and language level analyses, the primary aim of this study was to explore how the *delivery* (questions or statements) and *content* of teacher-child conversations in an inquiry-based preschool classroom emerges and changes during an extended scientific inquiry unit on forces and motion. We define inquiry-based learning as children actively constructing knowledge through asking questions, experimenting, evaluating evidence, and sharing information with others (Anderson, 2002; Edson, 2013; Haber et al., 2019). Before turning to the current study, we highlight prior work on how question-explanation exchanges and inquiry-based learning foster children's early science learning.

Question-Explanation Exchanges Foster Children's Early STEM Learning

According to *Helping Students Make Sense of the World Using Next Generation and Engineering Practices*, "making sense of the world beings with questions that identify what needs to be explained about the phenomena" (Reiser et al., 2017, p. 88). From an early age, children use question-explanation exchanges with adults to acquire knowledge about the world around them, especially in the science domain (Butler et al., 2020; Chouinard, 2007; Frazier et al., 2009; Hickling & Wellman, 2001; Kurkul & Corriveau, 2018; Legare et al., 2017; Ruggeri & Lombrozo, 2015; Tizard & Hughes, 1984). According to social interactionist theories of development and learning, such conversations with more knowledgeable others, such as teachers, scaffold children's understanding of scientific concepts during the preschool years (e.g., Leech et al., 2020; Vygotsky, 1978). Research utilizing naturalistic or semi-structured parent-child conversations (e.g., Callanan & Oakes, 1992; Chouinard, 2007; Greif et al., 2006) as well as diary methodologies (e.g., Callanan & Jipson, 2001; Callanan & Oakes, 1992) suggests that preschoolers (aged 3-5) ask primarily information-seeking (fact-based or causal) questions about a variety of topics including biological (e.g., "why do plants need sunlight to grow?"), natural ("e.g., "why does it rain?") and physical (e.g., "how are rainbows made?") scientific phenomena (Frazier et al., 2009; 2016; Hickling & Wellman, 2001; Kurkul & Corriveau, 2018; see Ronfard et al., 2018 for review; Saçkes et al., 2010; Saçkes et al., 2016). By five years of age, children can construct and express questions that are aimed at obtaining specific information about a topic or solving a problem (Legare et al., 2013; Mills et al., 2010, 2011; Ruggeri & Lombrozo, 2015).

Whereas children ask a similar number of fact-based ("what," "when," "who"; e.g., "where is the ramp?") questions throughout the preschool years, by four years of age, children shift to asking more causal questions ("why", "how"; e.g., "why does the marble fall off the ramp?), which are aimed at acquiring explanations about scientific concepts or mechanisms underlying causal processes (Chouinard, 2007; Leech et al., 2020). Further, research demonstrates that even three-year-olds ask their parents causal questions (Bova & Arcidiacono, 2013; Callanan & Oakes, 1992) and regardless of socioeconomic status (SES), preschoolers from families identifying as mid- and low-SES seem to direct a similar proportion of fact-based and causal questions to parents (Kurkul & Corriveau, 2018) and teachers (Kurkul et al., 2022). Although children's fact-based questions can often be answered with a one-word response, children's causal questions require more sophisticated explanations from parents, teachers, and other learning partners, which in turn, have the potential to foster children's early knowledge acquisition (Benjamin et al., 2010; Callanan et al., 1995; Jipson et al., 2016; Kurkul et al., 2021; Lombrozo et al., 2018).

A great deal of research has focused on how question-explanation exchanges in informal environments, such as the home setting or museum exhibits, shape children's science learning. In response to children's explanatory questions, parents scaffold science learning by providing causal explanations, helping children to test predictions, carry out experiments, and activate their prior knowledge. These dyadic exchanges support children in revising their beliefs about the world around them (Callanan et al., 2020; Crowley, Callanan, Jipson et al., 2001, Crowley, Callanan, Tenenbaum et al., 2001; Frazier et al., 2016; Gutwill & Allen, 2010; Haden, 2010; Haden et al., 2014; Jant et al., 2014; Kurkul et al., 2021; Leech et al., 2020; Mills et al., 2017). For example, Fender and Crowley (2007) found that when children (aged 3-8) heard explanations from parents during a science activity, they were more likely to acquire a conceptual as opposed to a procedural understanding of the task in contrast to children who did not hear explanations. Similarly, Willard et al. (2019) found that when parents were told to provide explanations to their children (aged 4-6) when interacting at a gears exhibit, children spent more time investigating with and talking about gears compared to parents who were only told to explore with their child. In recent work, Leech et al. (2020) and Kurkul et al. (2021) found that when parents provided explanations that included more mechanistic talk (highlighted cause and effect), their preschoolers (aged 4-5) were more successful at transferring the scientific knowledge to a novel STEM task. Taken together, these findings highlight how such conversations serve as a powerful mechanism for children's early science learning.

In the current study, we were particularly interested in exploring how preschoolers' information-seeking scientific questions emerge and change during an extended scientific inquiry unit in school. We argue that examining children's information-seeking questions longitudinally is imperative in deepening our understanding of how question-explanation exchanges develop and change as children gain more knowledge about scientific topics and how this may impact children's question-asking strategies. To date, prior work has looked at developmental changes in children's question-asking behavior by examining longitudinal transcripts of everyday conversations from the Child Language Data Exchange System (CHILDES) Database (e.g., Chouinard, 2007; Frazier et al., 2009; Hickling & Wellman, 2001). However, this work has mainly focused on the *process* of question-asking. Some diary studies of children's questions in the home indicate that when children learn content that is challenging to understand, such as death, they often revisit the same topic over the course of several days or weeks (Tizard & Hughes, 1984). We were particularly interested in how such 'passages of intellectual search' develop in a classroom setting. To the best of our knowledge, little research has examined variability in teacher-child scientific conversations (question-explanation exchanges) and language during an extended inquiry in a preschool classroom. Thus, in the current study, we focus on how such inquiry develops and changes over the course of month-long unit in a preschool setting.

Unlike when children interact with parents at home, in the preschool classroom context, the teacher must meet the demands of many children at once as well as adhere to pedagogical goals, which in turn, may impact the quantity and quality of such teacher-child conversations (Haber et al., 2021; Sak, 2020). For example, Tizard and Hughes (1984) found that whereas 3-year-olds asked parents about 26 questions per hour at home, they only directed about 2 questions per hour to teachers at school. In contrast to the abundant literature on how parent-child conversations can shape children's science learning during the preschool years, less work has focused on children's science questions in the preschool classroom and how teachers use a variety of pedagogical moves (or strategies for responding to questions) to foster their natural curiosity and science learning (e.g., Dean Jr. & Kuhn, 2007; Golinkoff & Hirsh-Pasek, 2016; Klahr & Nigam, 2004).

Recent research indicates that there are several ways for teachers to respond to children's questions in a classroom setting. First, teachers often respond to children's scientific questions by *providing an explanation* (Haber et al., 2021; Kurkul et al., 2022). During the preschool years, high-quality explanations, in response to children's information-seeking questions, may be a critical tool for supporting their science learning because they can provide information about abstract scientific processes that may be difficult to discern or observe on their own (Frazier et al., 2009; Legare & Lombrozo, 2014). For example, although a child may observe that some objects move faster or slower down a ramp, they may not understand the underlying concepts of force and gravity. Additionally, a child may notice that when a teacher flips a switch, a fan turns on in the classroom, but they are unable to view the circuit mechanism that causes this electrical process (Leech et al., 2020). Second, teachers can also guide children's STEM learning by *encouraging them to explore and construct their own explanation*. For example, when a child asks, "why do you need to elevate the ramp?" a teacher may respond by *turning the question back to the child* ("why do you think you need to elevate the ramp?"), providing children with learning opportunities to construct their own explanation (e.g., Skalstad & Munkebye, 2021). Indeed, in recent work Kurkul et al. (2022) found that in response to children's causal questions, teachers in mid-SES classrooms were likely to turn the question back to the child, potentially allowing them to hypothesize and consider their question more deeply. Third, teachers may scaffold science learning *by asking questions or clarifying children's explanations* that foster children's curiosity (Haber et al., 2021). Finally, teachers may *suggest an investigation* (e.g., "let's see if we can experiment with the height of the ramp"), highlighting a critical part of the scientific process. In sum, during the preschool years, teachers' responses to children's scientific questions create opportunities for children to develop scientific skills, which can also provide the foundation for children's later engagement and interest in STEM during formal schooling (Windschitl et al., 2017).

Beyond simply responding to scientific children's questions, teachers can use questions themselves as a pedagogical strategy to initiate inquiry and promote exploration in enhancing early STEM learning. In asking questions, particularly causal questions, teachers are demonstrating an important skill for children and facilitating their own ability to generate complex questions and use them effectively to gain information (Reiser et al., 2017). Through observing teachers asking scientific questions and engaging in an investigation to answer those questions, young children are learning how to successfully engage in science learning. Further, teacher-initiated questions can encourage children to generate their own explanations, which in turn, can impact their science learning (Harlen, 2001; Harlen & Qualter, 2004; Lee & Kinzie, 2012). For example, prior work has shown that elementary-aged students better understand and remember explanations that they have had an active role in constructing (McNeill et al., 2017). Thus, teacher-initiated question-explanation exchanges model and provide opportunities for children to generate scientific, causal explanations and plan out investigations, which are critical scientific practices that continue to develop during formal schooling (NRC, 2012).

Inquiry-Based Learning Supports Children's Early Science Knowledge

The current study explores how teacher-child question-explanation exchanges in an inquiry-based preschool classroom change during an extended scientific inquiry unit. According to the *National Science Education Standards*, "scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work" (National Research Council [NRC], 1996, p. 23). As mentioned above, to date, most prior work on children's science learning during the early years has focused on parent-child scientific conversations or their involvement in children's early science learning (e.g., Butler, 2020; Kurkul et al., 2022; Leech et al., 2020; Saçkes, 2014; Saçkes et al., 2019; Willard et al., 2019), a specific school curriculum (Peterson & French, 2008; Saçkes et al., 2020), targeted scientific inquiry skills (Lanphear and Vandermaas-Peeler, 2017; Saçkes, 2013), science and math-based classroom activities (Hobson et al., 2010; Inan et al., 2010; Saçkes et al., 2011; Lanphear & Vandermaas-Peeler, 2017) or brief, short-term conversations about variety of topics in the classroom (Kurkul et al., 2022). Although prior research has demonstrated how inquiry-based learning and question-explanation exchanges with parents and teachers foster children's early STEM learning and engagement; such approaches do not allow us to explore changes and variability in teacher-child conversations over time during an extended inquiry unit that arises based on children's interests in the preschool classroom.

We collected naturalistic classroom data from a preschool that emphasizes inquiry-based learning. In this preschool, teachers typically develop an annual extended inquiry unit based on children's interest in a particular topic (e.g., animals, cooking; Edson, 2013). Depending on children's interests, an extended inquiry typically lasts anywhere from a few weeks to months, allowing us to explore what teacher-child scientific conversations look like longitudinally and how they shape children's early STEM learning.

We had three main research questions. Our first research question explored variability in the frequency and type of questions that children and teachers ask during this extended inquiry. Here, we were particularly interested in information-seeking questions (causal, e.g., "how will you construct a pathway?"; fact-based, e.g., "where's the marble?"). We had two hypotheses. On the one hand, we speculated that because inquires often emerge based on children's curiosity and deepened interest in a topic, they may ask more causal questions at the beginning of the inquiry. On the other hand, we hypothesized that as children engage in the inquiry, they acquire more knowledge about the topic and thus, they transition to asking more causal (rather than fact-based) questions at the end of the inquiry.

Our second question asked how the frequency and type of statements that children and teachers produce change throughout the inquiry. Here, we were interested in causal explanations as well as language aimed at scaffolding the interaction and exploration. Our main hypotheses centered around teachers utilizing causal statements more in the early weeks of the inquiry to provide children with the necessary information to successfully engage with the inquiry, and transitioning to more scaffolding language encouraging children to construct their own knowledge as the inquiry progressed.

Finally, our third research question asked about the interactional quality of the language, that is how teachers and children responded to and prompted each other throughout the inquiry. Here, we were primarily focused on causal, fact-based, and scaffolding language and how these types of language interactions emerged and developed during the inquiry. In line with prior work (e.g., Chandler-Campbell et al., 2020), we predicted that causal language would prompt greater scientific content for teachers and children, whereas fact-based and scaffolding language would likely lead to more fact-based responses.

Method

Sample

The sample included eighteen videos (3 Weeks; 9 Days; 14 hours of video footage) from one mixed-aged, preschool classroom (19 children ranged from 2.9- to 5-years-old; 2 lead teachers; 2 directors) located in a Northeastern city in the United States. The preschool is primarily composed of children from White, middle-class backgrounds. However, about 10% of students also attend the preschool through scholarships and as such there is some sociodemographic diversity, though exact demographic information is not available for the students and teachers. Because this preschool is part of a teacher preparation program for preservice teachers, there are several microphones and cameras embedded in the ceiling of the classroom. The videos, which are typically used for pedagogical purposes, allowed us to record teacher-child naturalistic conversations during the scientific inquiry. The study was approved by the Institutional Review Board at Boston University. To ensure confidentiality and anonymity of the research participants, all data are kept in a secure format. In addition, we also conducted an interview with the lead teachers, who provided information about the development of the inquiry.

In consultation and collaboration with the lead teachers and directors of this preschool, we videotaped teachers and small groups of children in April 2019 about three times per week for the duration of the inquiry, which lasted about three weeks. This extended inquiry unit emerged based on children's interests in forces and objects in motion. Through our partnership with the preschool, we were able to capture and videotape the one-month inquiry as soon as children started asking questions about and experimenting with pathways and ramps. According to *Helping Students Make Sense of the World Using Next Generation and Engineering Practices,* "decisions on what to investigate and how to investigate should be motivated by questions arising from students' current explanations of phenomena and shaped in part by new science ideas that have been introduced" (Windschitl et al., 2017, p. 139). In designing this inquiry, teachers first observed how children were experimenting with wooden channels and objects in the block area, and then constructed central questions (e.g., "how far can you make your object travel?"), challenges (e.g., "construct a pathway system with 5 wooden channels"), activities, and assessment strategies that were aimed at children understanding concepts related to forces and the movement of objects on pathways and ramps. Given the topic of this extended inquiry, the videos focused on the block area of the classroom and brief conversations during morning meeting time that discussed the inquiry.

Transcription and Coding

In this study, we focused on ‘passages of intellectual search’ – children’s question-explanation exchanges focusing on a single topic over time – in a preschool classroom (Tizard & Hughes, 1984). We aimed to explore how questions and statements in science inquiry might change over the course of an extended inquiry in a preschool classroom. Consistent with prior work (e.g., Chandler-Campbell et al., 2020; Frazier et al., 2016, 2019; Kurkul and Corriveau, 2018), the unit of analysis for our results is the utterance, not the teacher or child.

All videos were transcribed at the level of the utterance by the first and second authors and a research assistant according to the conventions of Child Language Data Exchange System (CHILDES) (MacWhinney, 2000). After the video was transcribed, it was verified for the accuracy by an additional research assistant. Our coding scheme was adapted from previous work (e.g., Callanan et al., 2020; Chandler-Campbell et al., 2020; Medina & Sobel, 2020) and all utterances were coded for *delivery* (question, statement) and *content* (e.g., causal, fact-based, scaffolding; see Table 1).

Delivery Codes

All teacher and child utterances were first coded for *delivery* (see Table 1). We had two mutually exclusive categories: *question* (e.g., “what support should we start with?”; Line 24; Week 1, Day 1; “how will you close that gap?”; Line 9740; Week 3, Day 8) or *statement* (e.g., “you worked together to put the ramp back”; Line 787; Week 1, Day 1; “let me try”; Line 1890; Week 1, Day 2; “then it bounced off”; Line 8311; Week 3, Day 7).

Table 1. Coding scheme for data by delivery (questions, statements) and content (information-seeking questions/informational statements; noninformation-seeking questions and noninformational statements)

Coding Scheme		
Delivery and Content	**Explanation**	**Examples**
Delivery		
Question	All utterances that were aimed at eliciting information.	• What support should we start with?
Statement	All utterances that were a declarative sentence.	• You worked together to put the ramp back
Content		
Information-Seeking Questions/Informational Statements		
Causal	This code included all utterances that mentioned the causal mechanisms or processes between scientific facts.	• Why is everything getting stuck? • Why is it falling off there?
Fact-Based	All utterances were coded as fact-based/procedural that narrated steps to achieve a goal during the scientific activity or narrated actions, rather than explaining a scientific mechanism or process.	• What happened to the marble? • You created a design of the pathway system. • I am going to put five there.
Noninformation-Seeking Questions/Noninformational Statements		
Attention	All utterances that were aimed at seeking one’s attention by initiating an action or calling other participants.	• Are you ready? • See? • Alex?
Clarification	All utterances that were aimed at clarifying something that had been said received this code.	• What? • What do you mean?
Confirmation	All utterances that consisted or any low-effort utterances in response to preceding utterances.	• Yes • No
Scaffolding	All utterances that included directing and scaffolding questions or	• What do you think?

	statements aimed at telling someone what to do or suggesting a next step received this code. This included pedagogical moves such as turning the question back to the child.	• Let's see where it lands.
Reinforcing	All utterances aimed at reinforcing behavior or repeated the prior statements.	• That's good • Cool
Other	We coded for predictions, analogies, and references to the challenge of the day (central questions/goals teachers developed on days of the inquiry to guide children's exploration). Because these codes individually appeared less than 1.3% of the time in the overall data, we have collapsed them together into an *other* code.	• Do you think the small marble will roll faster or slower down the wooden channel? • This is like a tricycle.
Irrelevant	Any utterances that were either not relevant to the inquiry or utterances where the audio from the video recording was uninterpretable.	• There is space for you. • I want to play in a house.

Content Codes

After delivery, all utterances were coded for *content* (Chandler-Campbell et al., 2020). We had two main categories for content: *information-seeking questions/informational statements* (e.g., causal, fact-based/procedural; Chouinard et al., 2007; Kurkul & Corriveau; 2018) and *noninformation-seeking questions/noninformational statements* (e.g., scaffolding, confirmation, clarification, all remaining codes). Within the two categories, all content codes are mutually exclusive (see Table 1).

Coding Scheme for Information-Seeking Questions/Informational Statements. Utterances coded as information-seeking/informational subcategories included causal or fact-based/procedural talk.

Causal. This code included all utterances (questions and statements) that mentioned the causal mechanism or processes between scientific facts. For example, the teacher might ask, "why is everything getting stuck?" (Line 6995; Week 2, Day 6) or "why is [the marble] stopping over there?" (Line 8100; Week 3, Day 7), or "why is it falling off there?" (Line 8994; Week 3, Day 8). Additionally, when asked why the marble is stopping, a child might respond with, "there is a crack in [the pathway]" (Line 404; Week 1, Day 1).

Fact-Based/Procedural. All utterances (questions and statements) were coded as fact-based/procedural that narrated steps to achieve a goal during the scientific activity or narrated actions, rather than explaining a scientific mechanism or process (e.g., Chandler-Campbell et al., 2020). For example, a teacher might ask, "what happened to the marble?" (Line 8076; Week 3, Day 7) or a child pointing to an elevated pathway might ask, "what is that?" (Line 5335; Week 2, Day 5). Additionally, a teacher might say to the child, "you created a design of the pathway system!" (Line 2058; Week 1, Day 2) or a child adding wooden channels to the pathway might say, "I am going to put five there" (Line 5815; Week 2, Day 5).

Coding Scheme for Noninformation-Seeking Questions and Noninformational Statements. Utterances coded as noninformation-seeking/noninformational subcategories included scaffolding, attention, clarification, reinforcing, and confirmation talk.

Scaffolding an Action. All utterances that included directing and scaffolding questions or statements aimed at telling someone what to do or suggesting a next step received this code. This included pedagogical moves such as turning the question back to the child (e.g., "what do you think?") or utterances that scaffolding behavior (e.g., "let's see where that lands"). For example, a teacher might ask, "what are your ideas about this?" (Line 6303; Week 2, Day 5) or pointing to the pathway system, a teacher might say, "I wonder if you can draw a picture of this" (Line 8387; Week 3, Day 7). Additionally, a child might say, "let's see what the obstacle is going to do" (Line 3998; Week 1, Day 3).

Attention. All utterances that were aimed at seeking one's attention by initiating an action (e.g., "are you ready?" or "see?") or calling other participants (e.g., "Alex!") received an *attention* code.

Clarification. All utterances that were aimed at clarifying something that had been said received this code (e.g., "what?" "this way?"). For example, a teacher might say, "what do you mean?" (Line 6089; Week 2, Day 5).

Reinforcing. All utterances aimed at reinforcing behavior (e.g., "that's good", "cool") or repeating the previous statements received a *reinforcing* code.

Confirmation/Negation. All utterances that consisted or any low-effort utterances in response to preceding utterances (e.g., "yes" or "no") received this code.

Other. We also coded for predictions, analogies, and references to the challenge/question of the day (these were central questions or goals the teachers developed on given days of the inquiry to guide children's exploration). Because these codes individually appeared less than 1.3% of the time in the overall data, we have collapsed them together into an *other* code.

Irrelevant. Any utterances that were either not relevant to the scientific inquiry or any utterances where the audio from the video recording was uninterpretable received this code.

Reliability

The first and second authors independently coded the transcripts. Interrater reliability was established using a randomly selected sample of 22.22% of the transcripts. Reliability for *delivery* codes was 98% (Cohen's kappa = .95) and for *content* codes was 81% (Cohen's kappa = .76). Any discrepancies in coding were resolved through discussion.

Results

Analysis Plan

We employed language level analyses to investigate variability in how teacher-child scientific conversations (question-explanation exchanges) might change over the course of an extended inquiry on forces and motion, which in turn, has the potential to impact children's science learning during the preschool years. We first report the descriptive data for the inquiry, which includes the total percentages of overall talk for the entire inquiry by speaker (teacher, child), delivery, and content. Second, we report our longitudinal analyses exploring potential variability in the frequency and type of questions and statements by Speaker and Week during the inquiry. Finally, we report analyses examining the interactional quality of the language or how the type of replies given in response to information-seeking language and scaffolding language changes during the inquiry (Weeks 1, 2 & 3) and by speaker (child, teacher).

Descriptive Data

Table 2 displays the percentages of overall talk by *speaker* (teacher, child), *delivery* (questions, statements) and *content* (e.g., causal, scaffolding,). Overall, teachers and children produced a total of 11,476 utterances, with 49.67% total utterances from children (n = 5,700) and 50.33% from teachers (n = 5,776), χ^2 (1) = 0.5, $p > 0.05$.

Table 2. Percentages of overall talk (11,476 utterances) by speaker (child, teacher), delivery (questions, statements) and content

	Speaker	
Delivery and Content	**Child**	**Teacher**
Questions		
Information-Seeking*		
Causal%	11.84	23.2
Fact-Based %	88.16	76.8
Noninformation-Seeking*		
Attention %	12.45	3.54
Clarification %	21.13	45.89
Confirmation %	1.13	0.16
Scaffolding %	10.57	17.71
Reinforcing %	8.68	1.45
Other %	0.38	2.42
Irrelevant %	45.66	28.82
Statements		
Informational**		
Causal %	1.87	0.37
Fact-Based %	98.13	99.63
Noninformational**		
Attention %	7.68	7.77
Clarification %	0.06	0.31
Confirmation %	13.15	9.6
Scaffolding %	13.67	28.37
Reinforcing %	11.76	15.6
Other %	0.46	4.67
Irrelevant %	53.21	33.69

*Note. Information-seeking questions (causal and fact-based) were mutually exclusive. Thus, total information-seeking questions add up to 100% for each speaker. Similarly, all noninformation-seeking question codes were mutually exclusive and thus, all noninformation-seeking question codes add up to 100% for each speaker.

**Note. Informational statements (causal and fact-based) were mutually exclusive and add up to 100% for each speaker. Similarly, noninformational statement codes were mutually exclusive and add up to 100% for each speaker.

Delivery

We first coded all utterances in two mutually exclusive *delivery* categories: statements and questions. For *delivery*, we found that 18.14% (*n* = 2,082) of utterances were questions (72% from teachers and 28% from children) and 81.86 % (*n* = 9,394) of utterances were statements (45% from teachers and 54% from children).

Content

Next, we coded the *content* of each utterance, with seven mutually exclusive codes: *attention-seeking, clarification, confirmation, scaffolding, reinforcing, other* and *irrelevant*.

Questions. Questions were either coded as *information-seeking questions* (causal or fact-based; 57.44% of total questions) or *noninformation-seeking questions* (all remaining questions; 42.55% of total questions). For *information-seeking questions*, 20.15% were *causal* (*n* = 241) and 79.85% (*n* = 955) were *fact-based*. More specifically, we found that for teachers' *information-seeking questions*, 23.2% (*n* = 203) were *causal* and 76.8% (*n* = 672) were *fact-based*. For children's *information-seeking questions*, 11.84% (*n* = 38) were *causal* and 88.16% were *fact-based* (*n* = 283).

For *noninformation-seeking questions*, teachers and children asked primarily *scaffolding, attention-seeking* and *clarification* questions. More specifically, for teachers' *noninformation-seeking questions*, 45.89% (*n* = 285) were *clarification*, 17.7% (*n* = 110) and were *scaffolding*, and 3.54% (*n* = 22) *attention-seeking questions.* For children, 21% (*n* = 56) were clarification, 12.45% (*n* = 338) were *attention-seeking* and 10.56% (*n* = 28) were *scaffolding noninformation-seeking questions*.

Statements. Consistent with the questions, statements were either coded *as informational statements* (causal or fact-based; 31.99% of total statements) *or noninformational statements* (all remaining questions; 68% of total statements). For *informational statements*, we found that overall, 1.2% were causal (*n* = 36) and 98.8% (*n* = 2,970) were *fact-based*. More specifically, we found that for teachers' *informational statements*, 0.37% (*n* = 5) were *causal* and 99.63% (*n* = 1,339) were *fact-based*. For children's *informational statements*, 1.87% (*n* = 31) were *causal* and 98.13% (*n* = 1,631) were *fact-based*.

For *noninformational statements*, we found that teachers and children produced primarily *scaffolding, reinforcing, confirmation* and *attention-seeking* statements. Specifically, we found that for teachers noninformational statements (excluding irrelevant language) were mostly *scaffolding* 28.37 % (*n* = 833), *reinforcing* 15.6% (*n* = 458), *confirmation* 9.6% (*n* = 282) and *attention* 7.77% (*n* = 228) *statements*. Similarly, children (excluding irrelevant language), produced primarily *scaffolding* (13.67 %; *n* = 472), *confirmation* (13.15%; *n* = 282). *reinforcing* (11.76%; *n* = 406) and *attention* 7.68% (*n* = 265) *noninformational statements*.

Longitudinal Analyses

Table 3 displays the percentages of overall talk (for codes above 5% and excluding irrelevant language) for each *Speaker* (child, teacher) by *Week* (Weeks 1, 2 and 3), *Day* (Days 1-9), *delivery* (questions, statements) and *content* (e.g., causal, scaffolding) in the block area of the classroom. The remaining analyses focus on categories above 5% (excluding the irrelevant code). We first turn to longitudinal analyses on question-asking behavior during the inquiry, followed by changes in teachers' and children's statements.

Table 3. Percentages of talk for each speaker (child, teacher) by Week (Weeks 1, 2 and 3), Day (Days 1-9), Delivery (questions, statements) and Content

		Week and Day								
Delivery and Content	**Speaker**	**Week 1**			**Week 2**			**Week 3**		
		Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**	**Day 8**	**Day 9**
Questions										
Information-Seeking*										
Causal%	Child	3.8	0.0	2.2	0.3	0.6	1.9	0.3	1.3	0.9
	Teacher	3.5	1.8	4.1	2.1	2.6	4.7	1.7	1.4	0.8
Fact-Based/ %	Child	10.4	5.0	9.8	4.1	12.6	15.5	4.1	9.5	17.7
	Teacher	6.4	6.3	11.5	7.4	5.8	10.2	9.8	12.3	7.6
Noninformation-Seeking*										
Attention %	Child	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
	Teacher	0.7	0.5	1.2	0.5	0.2	0.2	1.0	0.5	0.2
Clarification %	Child	8.6	4.8	6.7	2.9	6.7	6.7	3.8	4.8	5.7
	Teacher	11.6	5.2	8.4	8.1	5.4	9.1	5.9	7.4	5.9
Scaffolding %	Child	3.8	8.6	2.9	0.0	8.6	2.9	0.0	0.0	0.0

	Teacher	3.2	3.5	8.4	3.0	2.2	0.5	1.5	1.0	2.2
Reinforcing %	Child	0.0	1.9	1.9	0.0	6.7	0.0	1.0	3.8	6.7
	Teacher	0.0	1.0	1.9	1.9	1.0	1.9	1.0	0.0	0.0
Statements										
Informational**										
Causal %	Child	0.3	0.2	0.4	0.2	0.0	0.2	0.1	0.3	0.1
	Teacher	0.0	0.1	0.2	0.1	0.0	0.0	0.1	0.0	0.0
Fact-Based/ %	Child	12.7	9.7	11.5	8.1	7.6	11.9	9.4	11.0	16.2
	Teacher	11.0	16.2	10.1	9.3	9.3	8.5	10.7	14.4	10.0
Noninformational**										
Attention %	Child	2.9	1.8	1.5	1.7	2.0	1.5	0.8	1.7	2.7
	Teacher	1.4	1.9	1.8	1.1	0.7	0.4	0.9	1.7	2.3
Clarification %	Child	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	Teacher	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0
Confirmation %	Child	5.5	2.8	2.6	2.0	2.3	3.7	2.5	2.7	4.0
	Teacher	1.4	0.8	2.6	1.4	1.4	2.4	1.3	2.5	2.1
Scaffolding %	Child	4.2	3.9	2.9	2.6	0.6	7.1	1.8	3.4	3.2
	Teacher	4.9	6.5	5.3	5.5	2.6	5.5	2.7	8.9	4.5
Reinforcing %	Child	3.9	2.8	1.3	3.0	1.7	3.0	3.7	3.4	2.5
	Teacher	2.2	2.6	4.3	2.5	1.7	3.9	3.0	2.1	2.7

*Note. Information-seeking questions (causal and fact-based) were mutually exclusive. Thus, the total information-seeking questions add up to 100% for each speaker across all 9 days. Similarly, all noninformation-seeking question codes were mutually exclusive and thus, all noninformation-seeking question codes add up to 100% for each speaker across all 9 days.

**Note. Informational statements (causal and fact-based) were mutually exclusive and add up to 100% for each speaker across all 9 days. Similarly, noninformational statement codes were mutually exclusive and add up to 100% for each speaker across all 9 days.

Questions

Overall, the number of questions significantly dependent on the Day and Speaker, χ^2 (8) = 76.99, $p <$ 0.01. Below, we explore changes in information-seeking and non-information seeking questions separately. We aimed to examine changes in questions by Day (Days 1-9) during the inquiry. However, for some codes, we did not have enough power to examine differences by Day (due to low frequencies) and in those cases, as we note below, we analyzed data at the Week level only (combining Days 1-3 for Week 1, Days 4-6 for Week 2, and Days 7-9 for Week 3).

Information-Seeking Questions. The number of *information-seeking questions* asked change significantly depending on the Day and Speaker, χ^2 (8) = 57.85, $p <$ 0.01.

Children's Information-Seeking Questions. To explore how the number of children's *information-seeking questions* change by Day, we conducted a poisson regression, finding that children's *information-seeking questions* significantly increased during Weeks 2 (Day 4 to Day 5; $\beta = 1.10$, $p < .01$) and 3 (Day 7 to Day 8; $\beta = .89$, $p < .01$; Day 8 to Day 9, $\beta = .55$, $p < .05$; see Table 3). Moreover, the timing of *fact-based* and *causal questions* for children varied. Follow up chi-squared analyses revealed that children asked more *causal questions* in earlier weeks (χ^2 (2) = 6.17, $p <$ 0.05), with over 78% of them occurring in Weeks 1 and 2. Note that due to low frequencies for the causal questions code, we analyzed causal questions by Weeks 1-3 and not individual Days 1-9. No significant changes in *fact-based questions* were observed across weeks (see Figure 1).

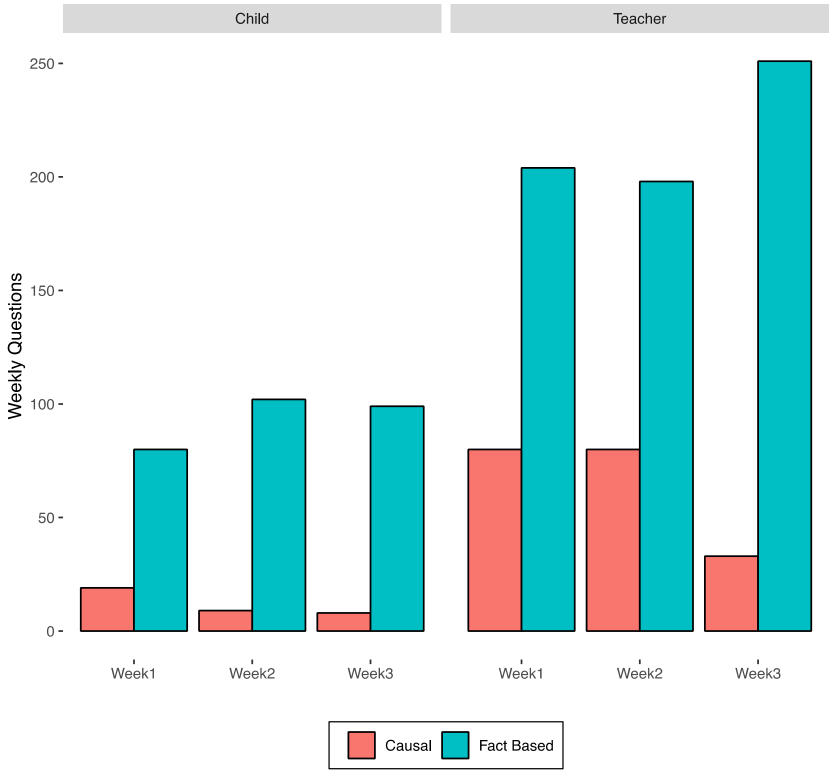

Figure 1. Frequency of information-seeking (causal and fact-based) questions by Speaker and Week during the extended inquiry.

Teachers' Information-Seeking Questions. We also explored how teachers' *information-seeking questions* change by Day through a poisson regression, finding that teachers' *information-seeking questions* significantly increased during Week 1 (Day 2 to Day 3, β = .66, $p < 0.01$), and Week 2 (Day 5 to Day 6: β = .57, $p < 0.01$) and significantly decreased in Week 3 (Day 8 to Day 9, β = -0.49, $p < 0.01$). Follow up chi-squared analyses revealed that teachers asked more *causal questions* in earlier weeks (χ^2 (2) =22.89, $p <0.01$; see Figure 1), with 82% of them occurring in Weeks 1 and 2. In contrast, teachers asked more *fact-based questions* in the later weeks of the inquiry (χ^2 (2) =7.74, $p < 0.05$), with 69% of them occurring in Weeks 2 and 3.

Noninformation-Seeking Questions. Next, we examined changes in *noninformation-seeking questions* during the extended inquiry by Day and Speaker. Analyses indicate that the number of *noninformation-seeking questions* asked change significantly depending on the Day and Speaker (χ^2 (8) = 32.01, p< 0.01).

Children's Noninformation-Seeking Questions. A poisson regression indicated that children's *noninformation seeking questions* did not change during Week 1 or Week 2, but did increase in Week 3 (Day 7 to 8, β =1.04, $p < 0.01$; see Table 3). For *scaffolding questions*, there were no significant changes between Week 1 and Week 2 (note that *scaffolding questions* were only observed on Days 1,2,3,5, & 6). Moreover, there were no significant changes in *clarification* or *reinforcing questions* in Weeks 1, 2 or 3. As illustrated in Figure 2, follow up chi-squared analyses revealed that children asked more *attention-seeking questions* in Week 3 (χ^2 (2) = 8.91, $p < 0.05$) compared to Weeks 1 and 2. Note that due to low frequencies for the attention-seeking code, we analyzed such questions by Weeks 1-3 and not individual Days 1-9.

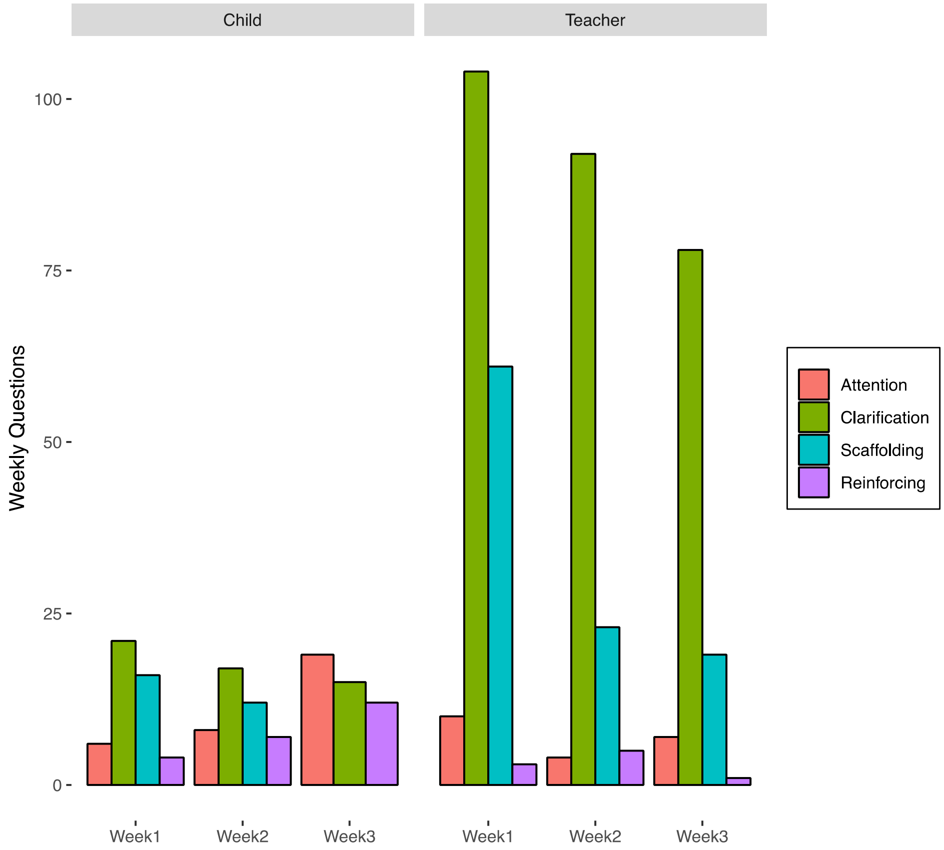

Figure 2. Frequency of noninformation-seeking (attention, clarification, scaffolding and reinforcing) questions by Speaker and Week during the extended inquiry.

Teachers' Noninformation-Seeking Questions. The results of a poisson regression indicate that teacher's *noninformation-seeking questions* changed in Week 1 (Day 2 to 3, $\beta = 0.57$, $p < 0.01$) and Week 2 (decreased from Day 4 to 5, $\beta = -0.61$, $p < 0.01$ and increased from Day 5 to Day 6, $\beta = 0.51$, $p < 0.01$), but did not change during Week 3 (see Table 3). Specifically, follow up chi-squared analyses revealed that teachers asked more *scaffolding questions* in Week 1 (χ^2 (2) = 31.30, $p < 0.001$; see Figure 2) in contrast to Week 2 and Week 3. There were no changes in teacher's *clarification* or *attention-seeking questions* in Weeks 1, 2 or 3. Finally, teachers asked no more than 5 *reinforcing questions* in any of the three weeks, so analyses were not appropriate.

In sum, for *information-seeking questions*, most of children's and teachers' *causal questions* occurred in the earlier weeks of the inquiry (Weeks 1 and 2), whereas for teachers, more *fact-based questions* occurred in the second half of the inquiry. For *noninformation-seeking questions*, children's *attention-seeking questions* appeared to increase by Week 3, whereas teachers asked more *scaffolding questions* during the beginning of the inquiry.

Statements

Overall, the number of statements significantly dependent on the Day and Speaker, χ^2 (8) = 140.25, $p < 0.01$. Below, we explore changes in informational and noninformational statements separately.

Informational Statements. We first explored changes by Day and Speaker in *informational statements* during the inquiry. Analyses indicate that the number of *informational statements* asked changed significantly by Day and Speaker (χ^2 (8) = 62.21, $p < 0.01$).

Children's Informational Statements. The results of a poisson regression indicate that children's *informational statements* changed in Week 1 (decreased from Day 1 to Day 2, $\beta = -0.27$, $p < 0.01$) and Week 2 (Day 5 to Day 6, $\beta = 0.48$, $p < 0.01$) and Week 3 (Day 8 to Day 9, $\beta = 0.37$, $p < 0.01$; see Table 3). Specifically, children produced 14 *causal statements* in Week 1, 8 in Week 2, and 9 in Week 3 and thus, no significant changes were observed across the inquiry unit. However, as illustrated in Figure 3, children's *fact-based statements* changed during Week 1 (decrease from Day 1 to Day 2, β = -.26, $p < 0.05$), Week 2 (Day 5 to Day 6, β = .46, $p < 0.001$) and Week 3 (Day 8 to 9, β = .39, $p < 0.001$).

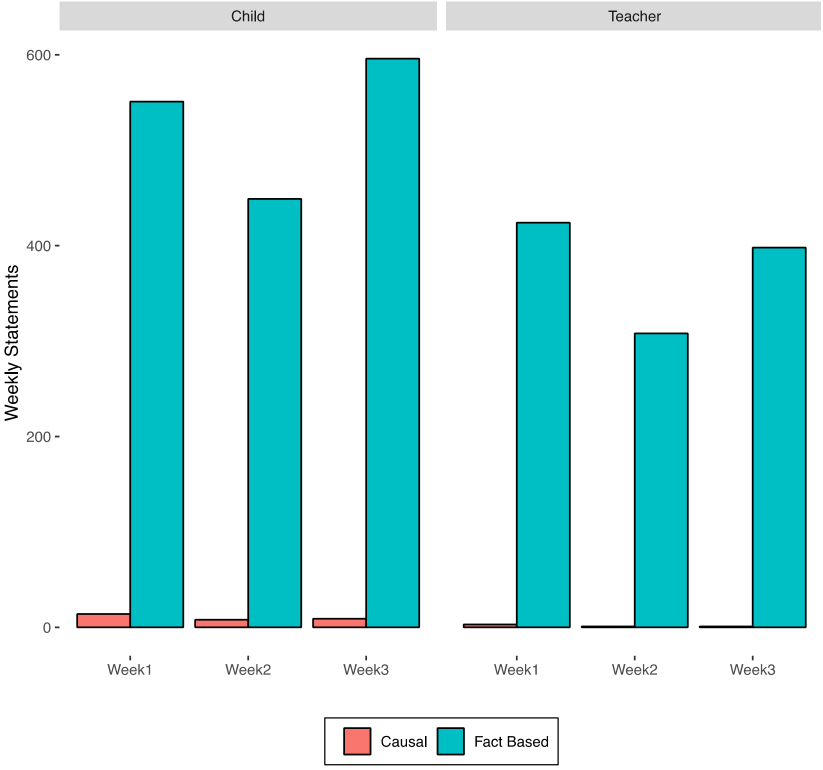

Figure 3. Frequency of informational (causal and fact-based) statements by Speaker and Week during the extended inquiry.

Teachers' Informational Statements. The results of a poisson regression indicate that teachers' *informational statements,* changed in Week 1 (Day 1 to 2, β = .39, $p < 0.05$ and decreased Day 2 to 3, β = -.46, $p < 0.05$) and Week 3 (Day 7 to 8, β = .29, $p < 0.05$ and decreased from Day 8 to 9, β = -.36, $p < 0.05$; see Table 3). More specifically, teachers produced 3 *causal statements* in Week 1, 1 in Week 2, and 1 in Week 3 and thus, no formal analyses were conducted on these frequencies. However, for teachers, *fact-based statements* changed in Week 1 (Day 1 to 2, β = .39, p < 0.001 and Day 2 to Day 3, β = .47, $p < 0.001$) and Week 3 (Day 7 to 8, β = .30, $p < 0.05$ and decreased from Day 8 to Day 9, β = -.36, $p < 0.01$; see Table 3).

Noninformational Statements. Finally, we explored changes by Day and Speaker in *noninformational statements* during the inquiry. Analyses indicate that the number of *noninformational statements* asked change significantly by Day and Speaker (χ^2 (8) = 130.63, $p < 0.01$).

Children's Noninformational Statements. The results of a poisson regression indicate that children's *noninformational statements* changed in Week 1 (decreased from Day 1 to 2, β = -.77, $p < 0.001$), Week 2 (decreased from Day 4 to 5, β = .20, $p < 0.05$ and increased from Day 5 to 6, β = .39, $p < 0.001$), Week 3 (Day 7 to 8, β =.49, $p < 0.001$; Table 3). Children produced more confirmation statements in Week 1 than Week 2 (χ^2 (2) = 6.93, $p < 0.05$; Figure 4). Children produced a similar number of *reinforcing statements, attention seeking statements, and scaffolding statements* across the three weeks (no changes were observed).

Teachers' Noninformational Statements. The results of a poisson regression indicate that teachers' *informational statements* changed in Week 1 (Day 2 to 3, β = .30, $p < 0.001$), Week 2 (decreased from Day 4 to 5, β = -.46, $p < 0.001$ and increased from Day 5 to 6, β = .37, $p <0.001$), and Week 3 (from Day 7 to 8, β = .75, $p < 0.001$ and decreased from Day 8 to 9, β = -.39, $p < 0.001$; see Table 3). Whereas teachers produced the fewest *attention statements* in Week 2 (χ^2 (2) = 10.80, p < 0.01; see Figure 4), teachers produced an equal number of *scaffolding, clarification, confirmation, and reinforcing statements* across the three weeks and thus, no significant differences in frequency were observed.

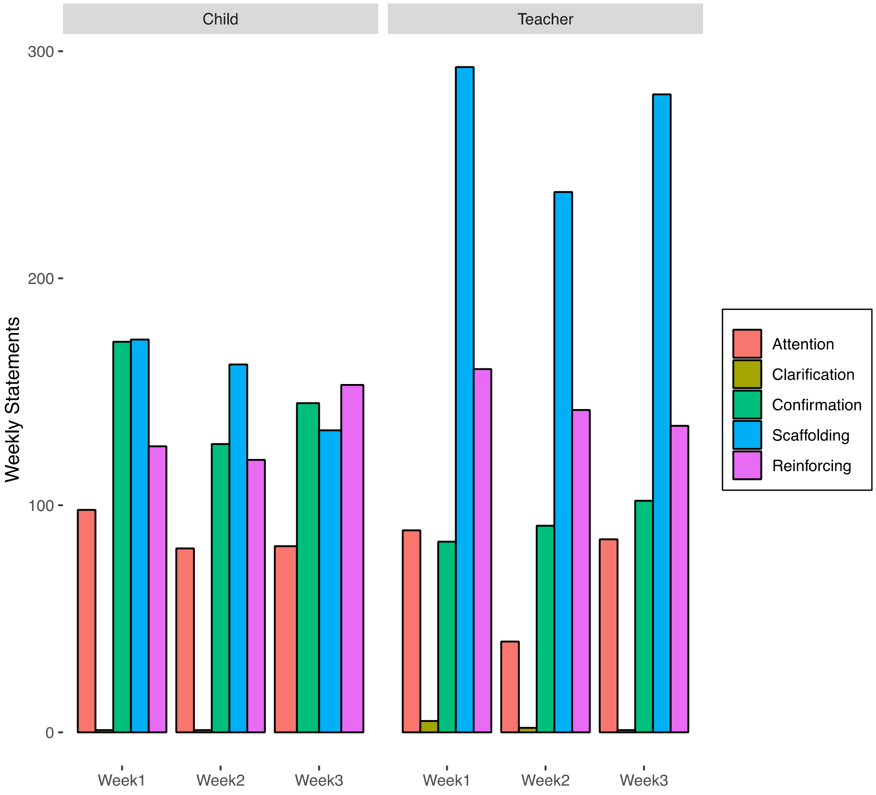

Figure 4. Frequency of noninformational (attention, clarification, confirmation, scaffolding and reinforcing) statements by Speaker and Week during the extended inquiry.

In sum, causal *informational statements* were quite rare for teachers and children, so there were no significant changes, but the number of *fact-based statements* increased throughout the inquiry. Children produced more *scaffolding and clarification statements* during the beginning of the inquiry, whereas teachers produced a similar number of such statements equally across the three weeks.

Interactional Quality of the Language: How did Teachers and Children Respond to Each Other Throughout the Inquiry?

Finally, we explored specific interactional patterns in the type of responses by teachers and children over the course of the extended inquiry. Accordingly, we identified all of the causal, fact-based and scaffolding utterances from our dataset and the subsequent utterance. For example, if a teacher or child asked a causal question, what was the type of response that followed and how did that change throughout the inquiry for each speaker? Across the three types of language (causal, fact-based and scaffolding), we examined changes in *delivery* (e.g., after someone produced causal language, was the following response a question or statement?) *content* (e.g., was the language fact-based, scaffolding, confirmation language?) and Speaker (child, teacher) by Week (Weeks 1, 2 and 3).

Table 4. Examining responses causal statements during the inquiry

	Causal Statements Model			
Variable	Estimate	(SE)	z	p
Week 1	0.15	(0.18)	0.82	.41
Week 3	-0.53	(0.22)	-2.41	.016*
Attention Statement	-1.39	(0.26)	-5.26	<.001***
Causal Statement	-1.71	(0.30)	-5.68	<.001***

Confirmation Statement	-1.28	(0.25)	-5.07	<.001***
Reinforcing Statement	-1.88	(0.32)	-5.80	<.001***
Scaffolding Statement	-1.28	(0.25)	-5.07	<.001***

*p <.05. **p<.01 ***p<.001

Fact-Based Language

To explore the types of responses that follow fact-based language (questions and statements), we first explored the *delivery* of responses (whether fact-based language results in responses that were questions versus statements). Collapsing across Speaker, the results of the first poisson regression indicated that although statements were more frequent than questions overall, the difference between statements and questions was smaller on Week 3 compared to Week 1 ($\beta = -0.25$, $p < 0.05$), but increased again from Week 2 to Week 3 ($\beta = 0.24$, $p < 0.05$; see Table 5).

Next, we examined the *content* of the statements given in response to fact-based inputs. The results of a second poisson regression revealed that fact-based statements (reference group) were more likely than any other kind of response (attention, causal, clarification confirmation, reinforcing, scaffolding) to follow fact-based language during the inquiry (see Table 6). Regardless of the *content* of the statement, there is a significant drop in responses from Week 1 to 2 ($\beta = -0.22$, $p < 0.001$), but a significant increase from Week 2 to 3 ($\beta = 0.35$, $p < 0.001$; Table 6). Finally, we examined potential speaker differences in responses to fact-based language, finding that fact-based statements were the most frequent response to fact-based language, as compared to any other type of statement (attention, causal, clarification, confirmation, reinforcing, scaffolding; see supplemental material). Regardless of the content of the statement, the frequency of teachers' responses decreased from Week 1 to 2 ($\beta = -0.24$, $p < 0.01$), but significantly increased from Week 2 to 3 ($\beta = 0.37$, $p < 0.05$). Similarly, for children, there was a significant decrease in responses from Week 1 to 2 ($\beta = -0.18$, $p < 0.05$), but a significant increase from Week 2 to 3 ($\beta = 0.34$, $p < 0.01$).

Table 5. Exploring how the delivery of responses (questions vs. statements) following fact-based language changes during the inquiry

	Delivery of Responses Following Fact-Based Language Model			
Variable	Estimate	(SE)	z	p
Week 1	-0.02	(0.1)	-0.244	0.81
Week 3	0.12	(0.09)	-2.41	.016*
Delivery Code (Statement)	1.1	(0.26)	0.08	<.001***
Week 1 Delivery Code (Statement)	0.25	(0.30)	0.11	.02*
Week 3 Delivery Code (Statement)	0.24	(0.25)	0.10	.02*

*p <.05. **p<.01 ***p<.001

Table 6. Examining responses to fact-based statements during the inquiry

			Fact-Based Statements Model	
Variable	Estimate	(SE)	z	p
Week 1	0.22	(0.05)	4.11	<.001***
Week 3	0.35	(0.05)	6.8	<.001***
Attention Statement	-2.05	(0.09)	-23.27	<.001***

Causal Statement	-4.15	(0.28)	-14.85	<.001***
Clarification Statement	-5.10	(0.45)	-11.38	<.001***
Confirmation Statement	-1.29	(0.06)	-20.17	<.001***
Reinforcing Statement	-1.24	(0.06)	-19.75	<.001***
Scaffolding Statement	-1.05	(0.06)	17.98	<.001***

*p <.05 **p<.01 ***p<.001

Scaffolding Language

Finally, we explored potential variability in the types of responses following scaffolding (questions and statements). We first explored the *delivery* of responses (whether scaffolding language results in responses that were questions versus statements). Collapsing across Speaker, the results of a poisson regression revealed that statements were more frequent overall (β = 1.56, *p* < 0.01). Furthermore, responses significantly decreased from Weeks 1 to 2 (β = 0.23, *p* < 0.01). Looking at the *content* of statements given in response to scaffolding inputs, the results of a poisson regression indicated that fact-based statements (reference group) were more likely than any other kind of response (attention, confirmation, reinforcing, scaffolding) to follow scaffolding language during the inquiry (see Table 7). Regardless of the content of statements, there was a significant decrease in responses from Week 1 to 2 (β = -0.28, *p* < 0.001). Finally, we examined potential differences in responses to fact-based language when the child or teacher was the speaker. Teacher fact-based statements were the more frequent response to scaffolding language, as compared to any other type of statement (attention, causal, clarification, confirmation, reinforcing, scaffolding; see supplemental material). Further, regardless of the content of the statement, there was a significant decrease in responses from Week 1 to 2 (β = -0.43, *p* < 0.01) and a significant increase from Week 2 to 3 (β = 0.33, *p* < .01). For children, scaffolding statements were more frequent than any attention, confirmation and reinforcing statements, but just as frequent as fact-based statements. No significant changes in response frequencies were found during the inquiry.

Table 7. Examining responses to scaffolding statements during the inquiry

			Scaffolding Statements Model	
Variable	Estimate	(SE)	z	p
Week 1	.28	(0.08)	3.58	<.001***
Week 3	.13	(0.08)	1.52	.13
Attention Statement	-1.8	(0.14)	-12.89	<.001***
Confirmation Statement	-1.37	(0.12)	11.73	<.001***
Reinforcing Statement	-1.08	(0.10)	-10.34	<.001***
Scaffolding Statement	-0.16	(0.08)	-2.08	0.037*

* p <.05. **p<.01 ***p<.001

Conclusion and Discussion

We utilized naturalistic classroom data and language level analyses to investigate variability in how teacher-child scientific conversations (question-explanation exchanges) may change over the course of an extended inquiry on forces and motion. We reasoned that such 'passages of intellectual search' would, in turn, have the potential to impact children's science learning during the preschool years. Overall, our results indicate that teachers and children (50.3% vs. 49.7% of total talk) produced a similar number of utterances during the inquiry. However, as we describe in detail below, we found that the quantity and content of children and teachers' questions and statements (explanations) varied throughout the three weeks. We first focus on the implications from the findings of our three research questions before turning to general limitations and future directions.

Is There Variability in Children and Teachers' Questions in an Extended Scientific Inquiry?

Our first question explored how the frequency and content of questions that children and teachers ask change during this extended inquiry. Overall, about 18% of utterances during the inquiry were questions, with almost 60% of them being information-seeking (causal and fact-based) questions. Further, almost three-quarters of questions were initiated by teachers during the inquiry. Recall that we had offered two hypotheses for how information-seeking questions might change during the inquiry. On the one hand, it seemed plausible that children might ask more causal questions at the beginning of the inquiry given that extended inquires often emerge based on children's curiosity and deepened interest in a topic. On the other hand, it also seemed possible that as children engage in the inquiry, they acquire more knowledge about the topic and shift from asking more simple fact-based questions to more complex, casual questions as the inquiry unfolds. In support of our first hypothesis, we found that children and teachers asked a greater number of causal questions in the earlier weeks of the inquiry (Weeks 1 and 2). Further, whereas children asked a consistent number of fact-based questions during the inquiry, teachers asked more fact-based questions in the later weeks (Weeks 2 and 3). Thus, it appears that during an extended scientific inquiry in the preschool classroom, causal questions are more present at the beginning of the inquiry, with fact-based questions following later to fill in additional information.

These findings confirm and extend prior research (e.g., Chouinard, 2007; Kurkul & Corriveau, 2018; Kurkul et al., 2022) demonstrating that during the preschool years, children ask information-seeking, primarily fact-based questions to acquire information specifically in the science domain. We argue that children's shift from initially causal questions early in the extended inquiry unit to more fact-based questions later in the unit reflect their natural curiosity about a topic and may signal to the teacher areas of confusion. Here, children were particularly interested in understanding how different objects travel on ramps and pathways. As the inquiry progressed, children acquired more knowledge about the topic (through asking questions, exploring, and experimenting), and their initial causal question-asking behavior declined. Thus, during the preschool years, it may be important for teachers to draw on children's inherent curiosity by providing opportunities for children to ask these explanatory, causal questions at the beginning of the inquiry or when introducing a new science topic/area in the classroom. Together, these findings advance our understanding of how children's questions serve as a power tool for acquiring knowledge from others by demonstrating variability in question-asking behavior around causal mechanisms and processes.

Recall that teachers' frequency of causal and fact-based questions also changed throughout the course of the inquiry. Whereas children's causal questions may reflect their own curiosity about the topic, we argue that teachers' causal questions serve a different pedagogical purpose (Osborne & Reigh, 2020). Approximately 25% of teachers' information-seeking questions were causal, with the majority of them occurring during the first half of the inquiry. In support of prior work advocating for teachers using questions as a pedagogical tool to model science investigation (Reiser et al., 2017), teachers' causal questions at the beginning of the inquiry may prepare children to further engage on their own. Further, just as turning a child's question back can encourage them to learn from and generate their own explanations (e.g., Skalstad & Munkebye, 2021), asking causal questions to the children may have served a similar purpose in providing learning opportunities as the inquiry began, which becomes less necessary as children learn and their understanding of the central themes of the inquiry develop.

Moreover, although there was not a great deal of variability in teachers' noninformation-seeking (scaffolding, clarifying, attention-seeking) questions, our analyses indicated that teachers seemed to ask more scaffolding questions at the beginning of the inquiry. We argue here that teachers might provide more support to children at the start of the inquiry to engage them in science learning through guiding them to ask questions, experiment, and explain their findings. However, as children become more involved in the inquiry, children may take on a more active role in their own learning, relying less on teachers' scaffolding questions to guide their learning. Together, these findings shed light on how teachers' questions during an extended scientific inquiry change in order to foster children's science learning at different stages of the inquiry. Further, even in an inquiry-based learning preschool classroom where children may be at the center of their own learning process (e.g., Edson 2013), teachers are still taking an active role in supporting children's learning, although this could change during formal schooling. This additionally highlights the iterative and collaborative process of science learning which has been revealed in recent work.

How Do Children and Teachers' Explanations and Statements Change and Develop During an Extended Scientific Inquiry?

Our second research question examined how the frequency and content of statements that children and teachers produce change throughout the inquiry, especially as it relates to causal explanations, and language aimed at scaffolding the interaction and exploration. Our main hypotheses focused on teachers providing a greater number of causal explanations in the early weeks of the inquiry to provide children with the necessary information to successfully engage with the inquiry, and transitioning to more scaffolding language as they encourage children to construct their own knowledge as the inquiry progressed. We found that causal statements were quite rare, comprising approximately 2% of informational statements for children and only .37% of informational language for teachers, and did not significantly vary during the inquiry. These results are consistent with previous work (e.g., Callanan & Oakes, 1992; Leech et al., 2020; Rowe, 2012; Tabors et al., 2001) demonstrating that explanatory talk is quite rare in everyday parent-child conversations, even when families are taught an inquiry-based intervention (e.g., Chandler-Campbell et al., 2020; Gutwill & Allen 2010). For example, Callanan and Oakes (1992) found that although children asked parents causal questions, they only provided such causal explanations about half of the time. Although generating and constructing scientific explanations is a critical skill that children develop during formal schooling (NRC, 2012; Next Generation Science Standards [NGSS], 2013), it appears that during the preschool years, such high-quality causal explanations are not as common. Whereas causal statements did not vary throughout the inquiry, our results indicate that teachers' fact-based statements increased over the course of the inquiry unit. Fact-based statements may work to scaffold children's early science learning through providing children with information that supports their own exploration and knowledge generation, such as where materials are or simple instructions that may further promote their ability to construct their own understanding of scientific topics. In short, teachers may be using use fact-based statements to foster children's autonomy in early science learning.

During the inquiry, teachers produced a similar number of noninformational statements (e.g., clarification, confirmation, scaffolding, reinforcing) when engaging with children. Why is there little variation in teachers' noninformational language? Although children are placed at the center of their own learning in an inquiry-based learning model, as they actively acquire information through asking questions and exploring, teachers still appear to play a critical role in guiding children's exploration by encouraging them (reinforcing language), trying to unpack their ideas (clarifying language), and suggesting actions or next steps (scaffolding). Because of the nature of the classroom context, we would expect to see teachers to provide a consistent level of support when interacting with children in the classroom, especially when they are inquiring about more complex scientific processes. As such, we would expect this reinforcing, clarifying, and scaffolding language to remain present at a stable level throughout the inquiry as they are continuously engaged in supporting children's exploration and learning. This teacher-initiated guiding language can enrich children's curiosity and even encourage them to ask additional questions (e.g., Engel, 2011).

How Do Teachers and Children Respond to and Prompted Each Other During an Inquiry?

Our third research question examined how teachers and children responded to and prompted each other during the inquiry, primarily focusing on causal, fact-based, and scaffolding language. In line with prior work (e.g., Chandler-Campbell et al., 2020) examining causal language in parent-child interactions, we speculated that causal language would prompt greater scientific content for teachers and children, whereas fact-based and scaffolding language would likely lead to more fact-based responses. However, we found that in response to causal language, both teachers and children were likely to respond with fact-based language. Recall that causal explanations were quite rare during the inquiry, suggesting that fact-based statements may be a strategic way to respond to causal questions; such statements can work to provide explanations and important information to help children understand causal mechanisms, even without specifically utilizing additional causal language. Consistent with our hypothesis, children and teachers were more likely to respond to fact-based and scaffolding language with statements that included more fact-based talk. A similar pattern was found for teachers' scaffolding statements: such statements also yielded fact-based language. Responses utilizing fact-based language are most natural when prompted with scaffolding or additional fact-based talk, for example if a teacher were to ask a child what they thought about where a piece goes, a scaffolding question, a child would most likely respond with a fact-based statement such as, "I think it goes there."

Limitations and Future Directions

Taken together, these findings provide insight into how children's and teacher's questions develop during an inquiry, informing our understanding of early science learning. However, there are several limitations of this work. First, although this preschool does include some children from lower-SES backgrounds, and families do represent a diverse range of racial and ethnic backgrounds (reflective of the local area), because the sample included teachers with higher levels of education and children were primarily from more mid-SES families, the results may not be generalizable to other settings. Specifically, these children and teachers may be more attuned to the types of conversation patterns that were the focus of the current study. For example, Kurkul et al. (2022) found that teachers in classrooms serving primarily mid-SES families were more likely than teachers in classrooms serving primarily low-SES families to respond to children's causal questions by turning the question back. Further, whereas children in mid-SES classrooms were likely to respond by generating their own explanations, children in low-SES classrooms often repeated their initial questions. Thus, future research should explore variability in teacher-child extended inquiry conversations in preschools that serve children from lower-SES backgrounds. Second, because this preschool emphasized inquiry-based learning during the preschool years, future work should extend such research to preschool classrooms that utilize other early childhood education philosophies or school curricula.

To examine how teachers' shape science learning during the early years, we chose to examine naturalistic teacher-child conversations in the classroom. However, this methodological, design choice did not allow us to directly assess children's science learning through formal assessments or pre/posttest questions. We argue that by examining naturalistic classroom data, the findings from this study can inform future research that directly examines children's learning outcomes or interventions designed to further enhance science talk in preschool classrooms. Nevertheless, future research should directly examine potential relations between the types of classroom discourse and children's knowledge acquisition.

In our future work, we are interested in examining two research questions. First, by following a small group (approximately 5 children) throughout the inquiry, we aim to further investigate potential individual differences in such scientific conversations during the preschool years. Second, we aim to explore how child characteristics (e.g., child gender) may contribute to variability in teacher-child conversations. For example, past research (Crowley, Callanan, Tenenbaum et al., 2001; Tenenbaum & Leaper, 2003) indicated that parents are more likely to provide scientific explanations to boys than girls and in the classroom setting, some of our current findings (Haber & Corriveau, 2021) demonstrates that teachers are more likely to direct causal questions to boys than girls in the preschool classroom. The current research points us closer to addressing these other research questions by demonstrating that there is variability in children and teachers' information-seeking questions during an extended inquiry in preschool.

In sum, these results provide insight into the development of children's and teacher's questions and explanations throughout an inquiry unit. Even in an inquiry-learning environment that values teacher-children co-construction of knowledge, teachers guide the interactions and ask questions to support children's learning. Our findings add to existing evidence that children's conversations with teachers play a critical role in scaffolding children's science learning during the preschool years. Specifically, children ask more, causal, explanatory questions at the beginning of the inquiry, suggesting that providing opportunities to ask questions may allow children to be more active in constructing scientific knowledge and building the foundation for their later engagement in STEM during formal schooling. Taken together, our findings are important for considering how science questions are naturally embedded in an inquiry-based learning preschool classroom and inform future research on the role of language in supporting children's early science learning.

Declarations

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Appendix

SUPPLEMENTAL MATERIALS

Interactional Quality of the Language: How did Teachers and Children Respond to Each Other Throughout the Inquiry?

Causal Language

The results of a poisson regression revealed that fact-based statements (reference group) were more likely than any other kind of response (attention, causal, confirmation, reinforcing, scaffolding) to follow causal language during the inquiry (see Table 4). Overall, trend observed for teachers (Table 8) and children (Table 9) was consistent, with fact-based statements being the more frequent response to causal language compared to any other type of statement (attention, causal, confirmation, reinforcing, scaffolding).

Table 8. Examining responses to teachers' causal statements during the inquiry

	Causal Statements Model			
Variable	Estimate	(SE)	z	p
Week 1	0.05	(0.21)	0.26	.8
Week 3	-0.76	(0.26)	-2.94	.003**
Attention Statement	-1.21	(0.28)	-4.27	<.001***
Causal Statement	-1.83	(0.47)	-3.87	<.001***
Confirmation Statement	-1.15	(0.28)	-4.16	<.001***
Reinforce Statement	-2.04	(0.40)	-5.09	<.001***
Scaffolding Statement	-1.22	(0.28)	-4.27	<.001***

* p <.05. **p<.01 ***p<.001

Table 9. Examining responses to children's causal statements during the inquiry

	Causal Statements Model			
Variable	Estimate	(SE)	z	p
Week 1	0.79	(0.42)	1.87	.06
Week 2	0.20	(0.49)	0.41	.68
Attention Statement	-1.94	(0.75)	-5.26	.001***
Causal Statement	-1.71	(0.30)	-2.59	0.056
Reinforce Statement	-1.50	(0.55)	-2.72	.006**
Scaffolding Statement	-1.18	(0.56)	-2.1	.036*

* p <.05. **p<.01 ***p<.001

Fact-Based Language

The results of a poisson regression revealed that fact-based statements (reference group) were more likely than any other kind of response (attention, causal, clarification confirmation, reinforce, scaffolding) to follow fact-based language during the inquiry (Table 6). The same trend was observed for teachers (Table

10) and children (Table 11), with fact-based statements being the more frequent response to fact-based language compared to any other type of statement (attention, causal, clarification, confirmation, reinforcing, scaffolding).

Table 10. Examining responses to teachers’ fact-based statements during the inquiry

			Fact-Based Statements Model	
Variable	Estimate	(SE)	z	p
Week 1	0.24	(0.08)	3.21	.001***
Week 3	0.36	(0.07)	4.95	<.001***
Attention Statement	-2.06	(0.12)	-16.96	<.001***
Causal Statement	-3.38	(0.38)	-8.84	<.001***
Confirmation Statement	-1.35	(0.09)	-15.00	<.001***
Reinforce Statement	-1.55	(0.1)	-15.91	<.001***
Scaffolding Statement	-1.19	(0.08)	-14.04	<.001***

* p <.05 **p<.01 ***p<.001

Table 11. Examining responses to children’s fact-based statements during the inquiry

			Fact-Based Statements Model	
Variable	Estimate	(SE)	z	p
Week 1	0.19	(0.08)	2.47	.01**
Week 3	0.35	(0.07)	4.78	<.001***
Attention Statement	-2.03	(0.14)	-15.94	<.001***
Causal Statement	-4.16	(0.41)	-10.12	<.001***
Clarification Statement	-4.34	(0.45)	-9.66	<.001***
Confirmation Statement	-1.23	(0.09)	-13.49	<.001***
Reinforce Statement	-0.97	(0.08)	-11.73	<.001***
Scaffolding Statement	-0.92	(0.08)	-11.30	<.001***

* p <.05 **p<.01 ***p<.001

Scaffolding Language

Looking at the *content* of statements given in response to scaffolding inputs, the results of a poisson regression indicated that fact-based statements (reference group) were more likely than any other kind of response (attention, confirmation, reinforce, scaffolding) to follow scaffolding language during the inquiry. The same trend was observed for teachers (Table 12), with fact-based statements being the more frequent response to scaffolding language compared to any other type of statement (attention, causal, clarification, confirmation, reinforcing, scaffolding). Whereas when the child was the initiator of the scaffolding input, the scaffolding statements were more frequent than any attention, confirmation and reinforcing statements, but just as frequent as fact-based statements (Table 13).

Table 12. Examining responses to teachers' scaffolding statements during the inquiry

	Scaffolding Statements Model			
Variable	Estimate	(SE)	z	p
Week 1	.43	(0.1)	4.21	<.001***
Week 3	.33	(0.1)	3.17	.002*
Attention Statement	-1.82	(0.17)	-10.94	<.001***
Challenge Statement	-3.16	(0.31)	-10.26	<.001***
Confirmation Statement	-1.71	(0.16)	-10.76	<.001***
Reinforce Statement	-1.46	(0.14)	-10.21	<.001***
Scaffolding Statement	-0.24	(0.09)	-2.65	0.008*

* p <.05. **p<.01 ***p<.001

Table 13. Examining responses to teachers' scaffolding statements during the inquiry

	Scaffolding Statements Model			
Variable	Estimate	(SE)	z	p
Week 1	.04	(0.13)	0.3	.70
Week 3	-.23	(0.14)	-1.72	.09
Attention Statement	-1.77	(0.25)	-6.96	<.001***
Confirmation Statement	-0.85	(0.18)	-4.82	<.001***
Reinforce Statement	-.03	(0.14)	-0.21	.84
Scaffolding Statement	-0.52	(0.16)	-3.27	0.001***

* p <.05. **p<.01 ***p<.001

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Research Article

Are preschoolers expected to learn difficult science constructs? A content analysis of U.S. standards

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Abstract: In the current paper, we report on the recommendations for preschool science put forward in the educational standards of U.S. states. Our focus was specifically on whether educational standards recommend abstract science constructs—constructs that are difficult to learn. In Study 1, we focused on science constructs related to *inquiry* (i.e., activities geared towards the generation of scientific knowledge). And in Study 2, we focused on science constructs related to *facts* (i.e., established scientific knowledge). In each study, we developed a coding scheme to distinguish between concrete and abstract constructs and then determined the relative prevalence of each. Our findings show that preschoolers are indeed expected to learn abstract science constructs. At the same time, educational standards varied considerably across U.S. states. Implications for the field of early science learning are discussed.

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Introduction

With science education becoming increasingly popular in preschool classrooms (Educational Development Center, 2013; National Center for Educational Statistics [NCES], 2021), many have hailed this development as a positive move toward supporting science learning in later grades (Guo et al., 2016; Piasta et al., 2014). In the current paper, we seek to further contribute to this development by asking a simple question: What is actually meant by preschool science? Our research was motivated by perceived points of tension in the field of early science learning. In what follows, we describe these points of tension and illustrate why they might need to be resolved before preschool science education becomes commonplace.

Tensions in The Field of Early Science Learning

Research on early science learning has increased substantially over the last three decades. For example, a search for the keyword "early science learning" on Google Scholar shows a three-fold increase in scholarly work over the years from 2000 to 2013 (from 250,000 to 850,000 entries). The search term "preschool science" reveals an even more dramatic increase during that time frame (from about 8,000 to 40,000 entries). This increase in scholarly work has led to important insights in the field (for reviews, see Guo et al., 2016; Kloos et al., 2012). Yet, the amount of scholarly work has decreased visibly recently (e.g., from about 40,000 to 29,000 "preschool science" entries in the years from 2015 to 2020).

Upon surveying the literature about what might be the issue, one finding was striking: Preschool teachers often have reservations about teaching science to young children (Park et al., 2017). For example, many teachers report that they do not have enough mastery of science content (Blonder et al., 2014; Oppermann et al., 2021). In turn, they might feel underprepared when using science materials (Kloos et al., 2018). Many also report lacking the confidence to organize the preschool classroom in ways that support science activities (Gerde et al., 2018). Teachers also perceive barriers when it comes to evaluating students

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on science assignments, compared to other fields (Greenfield, 2015).

More generally, the question of whether early science learning has positive long-term effects is still open. On the one hand, some have argued that mere exposure is enough to give children an advantage for later learning (e.g., Kachergis et al., 2019; Kelemen et al., 2014; Saidi & Sigauke, 2017; Shtulman et al., 2016; Worth, 1999). This argument might explain the numerous online resources designed to make science learning fun (e.g., education.com, 2012). On the other hand, science in preschool does not consistently translate into later science proficiency: Exposure to early science education might not predict improved science performance in older children (Brenneman et al., 2009; Saçkes et al., 2010; Saçkes et al., 2013).

There is also ambiguity about the amount of effort needed to bring science to young children. On the one hand, there is the appealing notion of science learning requiring nothing more than play, for example in nature (Erickson & Ernst, 2011; Eshach & Fried, 2005). This notion might drive the relatively low requirements for preschool instructors to learn science ahead of placement (U.S. Bureau of Labor Statistics, 2021). On the other hand, there are concerns that preschool classrooms might not be set up in a way that is conducive for science learning (Gerde et al., 2018). This is especially evident when science materials or designated science areas are missing (Tu, 2006).

Even the debate about whether young children can learn science constructs remains unresolved. On the one hand, there is great excitement about the potential of early science learning, based on the idea that children are natural scientists (e.g., Gopnik et al., 1999; Metz, 1995). On the other hand, science is known to be notoriously difficult, eliciting misconceptions and exasperating students in higher grades (e.g., Chi & VanLehn, 2012; Sawyer, 2006; Vosniadou, 2009). Indeed, scholars have raised concerns about the fact that preschoolers and kindergarteners show little improvement in science achievement after participating in science readiness programs (Greenfield et al., 2009; Saçkes et al., 2010).

These points of tension—whether on learning readiness, long-term benefits of early science learning, or required resources for preschool science pedagogy—are likely to add uncertainty to the field. At the minimum, points of tension might undermine efforts to make science a central part of early learning. For example, open questions on whether young children are cognitively ready to comprehend science constructs hamper curriculum decisions. And open questions on how to best prepare preschoolers for science learning impede the development of teacher-training modules. Thus, to promote scholarly work in the field, points of tension need to be resolved first.

Understanding the Nature of Preschool Science

One way to respond to tensions in the field is to explore the underlying assumptions that sustain disagreements (Dahl, 2017). In the case of early science learning, one underlying assumption pertains to the nature of preschool science. Those who assume young children are ready for science might intuitively equate preschool science with constructs that can be learned easily at an early age. Vice versa, those who assume protracted learning might intuitively equate preschool science with constructs that are difficult to learn at a young age. Thus, there might be divergent views on what is meant with science at the preschool level. If we could provide data on the nature of preschool science, we could address the tension and therefore contribute to progress in the field.

For questions about the nature of subject matters, important insights can be gained from educational standards. Incidentally, all of the 50 U.S. states put forward recommendations about early science learning (Kloos et al., 2018). They are organized into content domains such as life science, physical science, and earth/space science (e.g., Larimore, 2020; Saçkes et al., 2009). For example, educational standards for preschool science recommend that preschoolers learn about the differences between plants and animals (life science), the properties of light (physical science), and the day-and-night cycle (earth/space science).

To what extent do educational standards recommend science constructs that are difficult for preschool children? The idea is that construct difficulty is central to the question of whether young children can benefit from exposure to science content. If educational standards recommend science constructs that young children can easily learn, we can assume that young children are ready to learn about science. If, on the other hand, educational standards recommend science constructs that are difficult for young children, then we can assume that young children are ill-equipped for science learning. Thus, construct difficulty is a relevant dimension by which to characterize the nature of science.

The idea of learning difficulty is fundamental to the field of cognitive development. Indeed, numerous measures have been proposed to capture the learning difficulty of concepts, including relational complexity (Andrews & Halford, 2002), feature density (Gentner & Kurtz, 2005; Kloos & Sloutsky, 2008), or hierarchical position (Kloos et al., 2019; Rosch, 1978). Most prominent is the distinction between concrete and abstract concepts (Crain, 2015; Flavell, 1982; Piaget & Inhelder, 1969). Concrete concepts can be learned easily because they represent the immediate here-and-now. Abstract concepts, on the other hand, require a cumbersome form of integrating otherwise separate pieces of information (Chambers, 1991; Dumontheil, 2014; Huitt & Hummel, 2003).

The distinction between concrete and abstract constructs fits well within the realm of science constructs. Learning about different body parts, for example, could be thought of as concrete: Students merely need to attend to obvious entities (e.g., "head," "shoulders"). Learning about the differences between plants and animals, on the other hand, could be thought of as abstract: Students have to attend to potentially hidden features (e.g., the ability of an entity to self-propel), while ignoring superficial but highly salient features (e.g., the color and size of an entity). Learning about constructs such as the properties of light or the day-and-night cycle could also be thought of as abstract: Students need to keep track of events over time and detect a common thread among them. Thus, the distinction between concrete and abstract constructs can be useful for examining the nature of preschool science.

Overview of The Current Research

The goal of the current study was to explore the difficulty of science constructs specified in educational standards. To do so, we carried out a content analysis of the educational standards put forward by the U.S. states. A content analysis is a systematic way of analyzing text in which the relative presence of target concepts can be determined (DeCuir-Gunby et al., 2011; Dinçer, 2018; Eğmir et al., 2017; Krippendorf, 1989; Larson & Rahn, 2015). In Study 1, we focused specifically on scientific *inquiry:* the process by which science knowledge is developed (e.g., "doing science"; Seefeldt & Galper, 2007). In Study 2, we focused on science *facts:* the established insights that make up the corpus of science knowledge (e.g., "content knowledge"; Guo et al., 2015). In each case, we asked whether young children are expected to learn about abstract (i.e., difficult) science constructs.

Study 1: Abstraction in Inquiry

Are preschool children expected to engage in the types of inquiry activities that require abstract thought? To answer this question, we first developed a coding system that could capture the abstraction level of different forms of inquiry. We then applied the identified codes to the U.S. educational standards.

Method

Preparation of content

The documents used in our content analysis were the publicly available U.S. readiness standards for science learning in preschool. These standards consist of bullet points in lists, charts, and diagrams, organized by headings and subheadings. Given the inconsistencies between headings across states, we opted to omit them, focusing instead on the bullet-point entries. To be included in the content analysis, a bullet-point entry had to be targeted for children between 36 to 60 months of age. The entry also had to be listed in a section labeled as science (or under similar headings, such as STEM).

Once bullet-point entries were isolated (N = 1060), we delineated them into individual *items*. Each item contains a separate science requirement for preschool science. In most cases, one bullet-point entry corresponded to one item. However, when a bullet-point entry contained multiple sentences that included separate requirements, the entry was split into multiple items. We split 17 bullet-point entries in this way.

Next, we identified the *inquiry terms* of each item. Inquiry terms are the phrases that capture an inquiry activity. This could pertain to single verbs (e.g., "observe"), or it could pertain to entire verb phrases (e.g., "make a prediction").

In the process of identifying inquiry terms in items, we encountered action terms that were only tangentially related to science. Such terms focused on engineering (e.g., building something), math (e.g., counting), or the like. We refer to these terms as *non-science* terms (see Appendix A.1 for detailed information about the codes for non-science terms). Items that consisted entirely of non-science terms, without any scientific inquiry terms, were excluded. The final number of items included in our content analysis was 959 (range per state: 4 to 38 items).

Coding Scheme

The coding scheme we developed for inquiry terms contained nine codes, ranging from lowest to highest level of abstraction (see Table 1 for a summary). Our scheme drew on two theoretical frameworks: The Scientific Method (i.e., the guide to the development of scientific theories; Gerde et al., 2013) and Bloom's Taxonomy (i.e., a list of activities, organized hierarchically to lead to increasingly deeper learning; Airasian et al., 2001; Hepburn & Andersen, 2021). Below, we explain each code and the rationale for its assigned level (see Appendix A.2 for additional details on how each inquiry term was coded).

Table 1. Levels of scientific inquiry

Level	Category	Description
1	Observe-without-tools	Uses senses to observe what is most salient
2	Observe-with-tools	Uses tools to enhance senses when noticing what is most salient
3	Communicate-without-tools	Communicates understanding, thoughts, etc. in verbal or nonverbal ways
4	Communicate-with-tools	Uses tools such as graphs to communicate thoughts
5	Ask-questions	Expresses confusion or interest about missing information
6	Compare-contrast	Recognizes similarities and differences between entities
7	Predict	Makes an informed guess based on previous experience or understanding
8	Test-a-prediction	Experiments with variables to test hypotheses
9	Explain	Generate explanations for why and how things happen

Low Abstraction

At the lowest degree of abstraction (Levels 1-2), inquiry codes pertain to observing the surroundings. Our thinking was that observations require very little abstraction, if any: Children merely have to look at what is most salient in front of them, without needing to imagine hidden connections. Here, we distinguished between the *observe-without-tools* code (Level 1) and the *observe-with-tools* code (Level 2). Example tools for observation include magnifying glasses, microscopes, or measuring cups. The idea was that observations with tools require children to bridge between what entities look like when perceived with tools versus without them, which increases the level of abstraction compared to mere observations.

Medium Abstraction

At a medium degree of abstraction (Levels 3-5), inquiry codes pertain to communicating about the surroundings. Here, we distinguished between communicating with or without tools, as well as asking questions. Specifically, the *communicate-without-tools* code (Level 3) pertains to activities such as identifying or recognizing entities (e.g., "know vocabulary"), describing or talking about events ("recall"), or responding to prompts (e.g., "answer questions," "give examples," "confirm"). This code also includes action phrases that refer to more specific forms of communication (e.g., "use evidence," "offer critiques," "interpret observed events") and non-verbal communication (e.g., "draw," "take pictures," "record data").

The *communicate-with-tools* code (Level 4) applies when specific tools are listed to enhance communication (e.g., "create graphs," "tally observations," "use models of what is observed," "create displays"). Our thinking was that the use of these tools requires children to organize information in ways that are more abstract than merely retelling unorganized information. The *ask-questions* code (Level 5) applies when the activity of communicating requires children to make connections between what they already know and what they do not yet know (e.g., "be curious," "show interest," "express wonder"). Here, our thinking was that the activity of asking questions requires an awareness of something that is missing, which makes it more abstract than merely talking about available information.

High Abstraction

Finally, at the highest degree of abstraction (Levels 6-9), inquiry codes pertain to identifying, integrating, or manipulating variables. Here, we distinguished between comparing and contrasting entities, making or testing predictions, and generating explanations. Specifically, the *compare-contrast* code (Level 6) applies to activities in which one or more variables have to be identified against the backdrop of irrelevant aspects (e.g., "analyze data," "sort"). Adding a layer of abstraction, the *predict* code (Level 7) involves anticipating events in the future by drawing inferences from current circumstances (e.g., "formulate a hypothesis," "make guesses").

Adding yet another layer of abstraction, the *test-a-prediction* code (Level 8) applies to activities in which a variable has to be manipulated to determine its relation to another (e.g., "test hypotheses," "verify predictions"). This requires not only identifying variables, but also creating a setting in which an otherwise hidden relation between variables can be uncovered. Finally, the *explain* code (Level 9) applies to activities in which the relation between variables is supplemented with a narrative that goes beyond the immediately available findings (e.g., "make conclusions," "generalize"). This activity is arguably the pinnacle of scientific inquiry: It requires the detection of an otherwise invisible causal chain among variables.

Unspecified Terms

In addition to the nine abstraction levels, we also identified action phrases that were too vague to apply to a unique abstraction level. An example of such a term is to "explore": This activity could refer to something as concrete as observing the surroundings (Level 1), or to something as abstract as designing an experiment to test a prediction (Level 8). Thus, this term could not be assigned a code unambiguously (consider also "become familiar," "develop an awareness," "learn"). Given this ambiguity, we established an *unspecified* code for these terms.

Coding Procedure

Coding of action phrases was carried out iteratively: It started with an initial definition of codes, which was given to two coders who reviewed the items independently from each other. Disagreements were then discussed, resulting in a revision of the code definitions to either adjust or clarify the codes. In the final iteration, three coders reviewed the database of coded items and checked each item's codes independently from the other coders. Disagreement was then discussed a final time, again resulting in adjustments to the coding scheme. Given the consensus approach taken to discussions at each iteration, all items yielded 100% agreement.

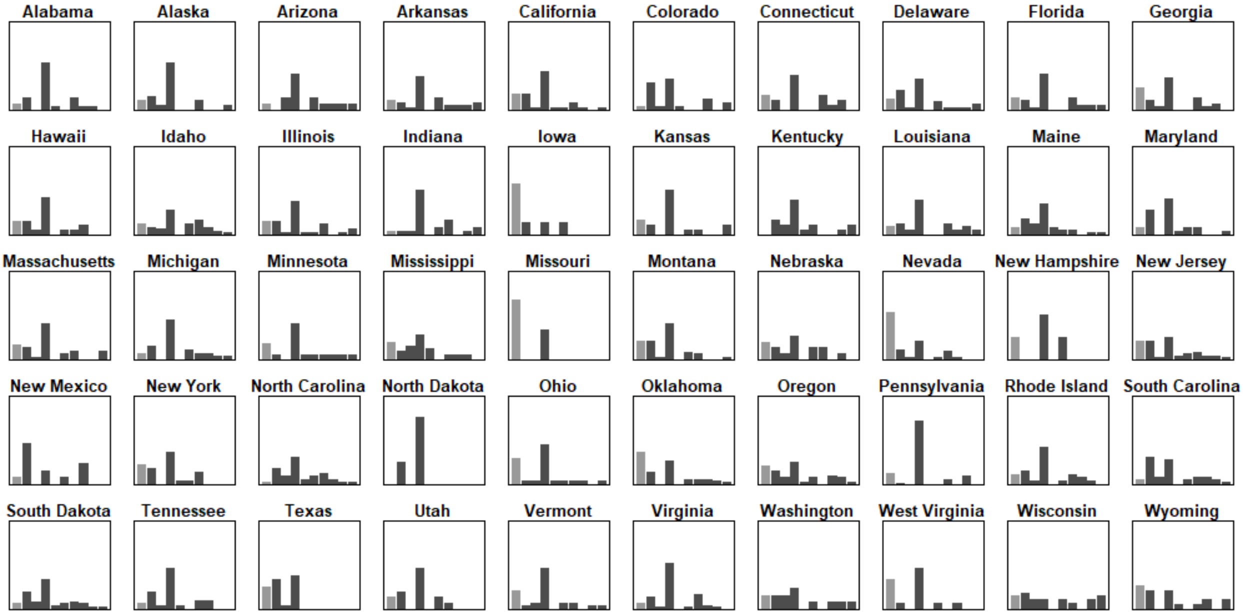
Results

Results are presented in three sections: The first section provides general information about how the educational standards differ among states. We then consider the broad distinction among the three degrees of abstraction (low, medium, high). Finally, we look more specifically at the prevalence of the four codes at the highest degree of abstraction.

Differences Among States

We found numerous ways in which state standards differed, starting with the number of items they listed: Some states had as few as 4 items, while others had over 20 items (see Appendix B.1 for the number of inquiry items and terms by state). Items also differed in their length: While some items consisted of just 2 words, others contained more than 20 words. The specificity of the content differed, too. While some items were vague (e.g., "use senses to experience something and make one or two comments to describe this"), others provided explicit examples (e.g., "observe processes and relationships, for example by using measuring cups to measure fish food, then observing fish and recording how much they eat").

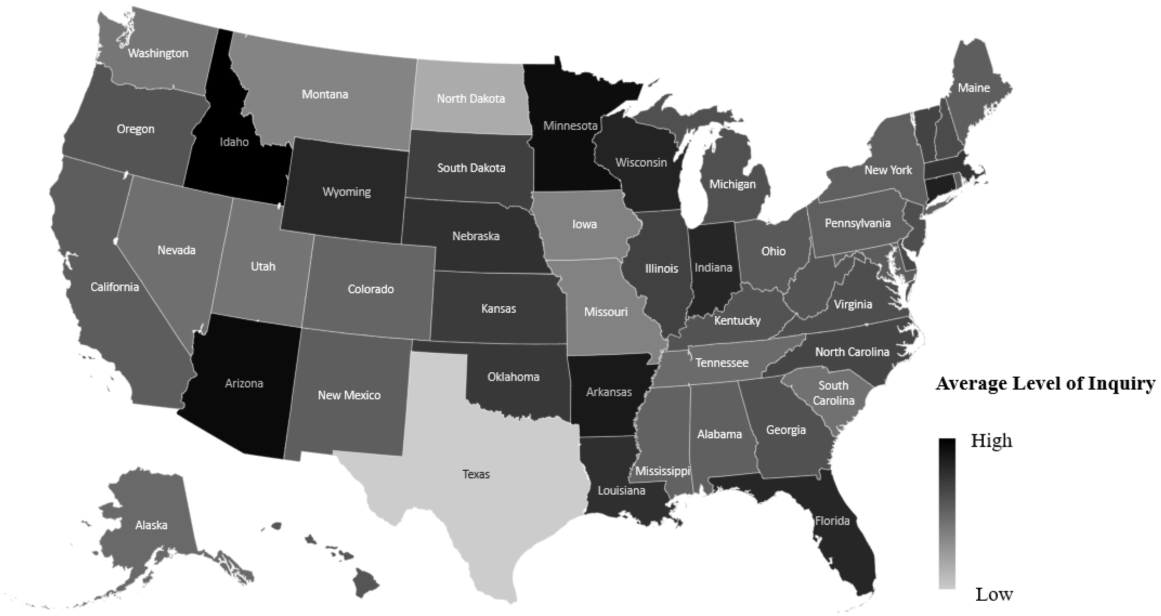
State standards also differed in what kind of inquiry they required of preschoolers. For example, while most standards used relatively few unspecified inquiry terms, some standards used primarily unspecified inquiry terms (6%). More to the point of abstraction levels, while some state standards covered every one of the nine abstraction levels (6%), other state standards restricted themselves to no more than three abstraction levels (10%). Figure 1 shows the prevalence of each abstraction code, separated by state.



Note. Light bars show the proportion of *unspecified* inquiry terms. Dark bars show the proportion of *specified* inquiry terms. The specified inquiry terms include: *observe-without-tools*, *observe-with-tools*, *communicate-without-tools*, *communicate-with-tools*, *ask-questions*, *compare-contrast*, *predict*, *test-a-prediction*, and *explain*. The specified inquiry terms are ordered from lowest to highest abstraction level.

Figure 1. Inquiry terms by state

We calculated an average abstraction level for each state, building on the idea that the nine levels of abstraction are ordered from lowest to highest. Specifically, we first calculated an average abstraction score for each item, and then we averaged across those scores for each state (excluding unspecified terms). Figure 2 shows the obtained results: While some state standards recommended inquiry at relatively high levels of abstraction (over 4.00, 20% of standards), the abstraction levels for inquiry recommended in other state standards was low (under 3.00, 4% of standards).



Note. The lowest possible score was 1 (*observe-without-tools*), and the highest possible score was 9 (*explain*). State averages range from 2.06 ("Low") to 4.65 ("High").

Figure 2. Map of average abstraction level

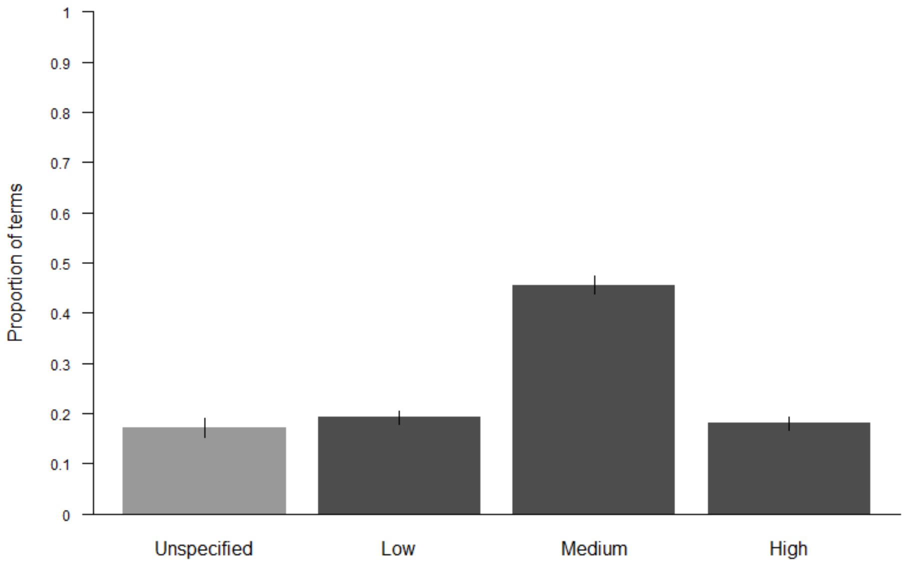
Broad Contrast Among Degrees of Abstraction

Next, we sought to capture broad trends across the U.S. standards. To do this, we calculated the proportion of inquiry terms that were of low (i.e., observing phenomena), medium (i.e., communicating about science), and high degrees of abstraction (i.e., attending to variables) and averaged them across states. Figure 3 presents the obtained results: The most common inquiry terms were at a medium degree of abstraction (*M* = 46%, *SD* = 12.16). Inquiry terms at the low degree of abstraction were less prevalent (*M* = 19%, *SD* = 9.76). They matched in prevalence with the high-abstraction inquiry terms (*M* = 18%, *SD* = 9.00).

Many state standards (44%) followed the overall pattern found across the U.S. states: Many featured a large number of medium-abstraction codes, and many featured approximately equal numbers of low- and high-abstraction codes. Thus, high-abstraction inquiry, while not the most prevalent, was nevertheless prominently featured in the educational standards—as prominent as low-abstraction inquiry. In fact, nearly all state standards (90%) required at least some high-abstraction inquiry. Considered together, high-abstraction codes accounted for 23% of the total specified inquiry terms.

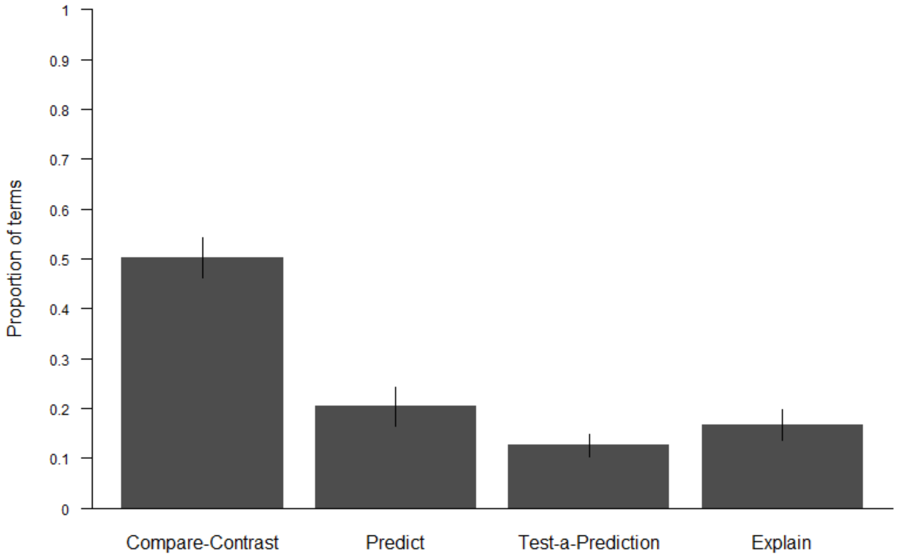
Specific Contrast Among High-Abstraction Codes

Finally, we sought to provide details on the type of inquiry required at the high end of the abstraction spectrum (*compare-contrast, predict, test-a-prediction, explain*). Figure 4 provides these data averaged across state standards. Of the four types of high-abstraction codes, the *compare-contrast* code was most prevalent (42%), occurring approximately twice as often as each of the other three types of high-abstraction codes. Indeed, this is the most prevalent of the high-abstraction codes for many states (54%), and most states feature at least one *compare-contrast* term (87%). The most common inquiry terms from this category were "differentiate" and "categorize."



Note. Proportions were averaged across states. The light bar shows the average proportion of *unspecified* terms. The dark bars show the average proportions of *specified* terms (low, medium, or high degree of abstraction). Error bars represent the standard error of the mean.

Figure 3. Average Proportion of Inquiry Terms



Note. Proportions were averaged across states. Error bars represent standard errors of the mean.

Figure 4. Proportion of high abstraction inquiry terms

The other three types of high-abstraction codes, though less prevalent than the *compare-contrast* code, were nevertheless represented in many state standards. For example, the *predict* code appeared at least once in 67% of the states. The most common terms of this type of abstraction were “hypothesize” and “anticipate”. Likewise, the *test-a-prediction* code appeared at least once in 64% of the state standards. The most common terms of this type of abstraction were “test hypotheses” and “experiment.” Even the highest level of abstraction, the *explain* code, appeared in many states at least once (67%). The most common terms of the *explain* code were “explain” and “generate conclusions.”

Discussion

In Study 1, we sought to characterize the level of abstraction present in scientific inquiry. Our results show that abstract scientific inquiry is indeed expected in U.S. preschools, at least to some extent. We found that the most prevalent inquiry activity is that of communicating. On some level, this might be expected, given that children's communicative behavior allows teachers to gauge their students' understanding (Brenneman, 2011). At the same time, this type of inquiry—to recognize things, learn science vocabulary, and discuss observations—is far from trivial for young children. Further, state standards were largely consistent in requiring high degrees of abstraction in inquiry. In fact, many standards specified that young children should engage in all levels of high-abstraction inquiry, including to test predictions and formulate explanations.

Study 2: Abstraction in Science Facts

In Study 2, we sought to characterize the level of abstraction present in science facts. That is to say, we asked whether preschool children are expected to learn about abstract content in the corpus of established scientific knowledge. To answer this question, we developed a coding system to capture abstraction in science facts and then applied it to the educational standards that contained facts.

Method

Preparation of content

To prepare the content of this analysis, we started with the 959 science items used in Study 1. First, we identified the domain of science that each item belonged to. Our rationale was that scientific facts can be analyzed best if they are specific enough to fit within a domain of science. Or, put differently, if content cannot be attributed to a domain of science, then it is likely to be too vague to allow a designation of concrete versus abstract content. Domains of science pertained to topics such as *life science* (e.g., biology), *physical science* (e.g., physics), or *earth/space science* (e.g., astronomy). Some items were coded as *other science* (e.g., social science, environmentalism) or *multiple sciences* (e.g., a combination of domains). Appendix A.3 provides details on how the domains of science were defined.

We excluded a total of 271 items that either had no content at all (*n* = 188, e.g., "discuss predictions"), were too vague to attribute to a specific domain of science (*n* = 74, e.g., "collect data"), or were too general to determine their abstraction level (*n* = 9, e.g., "understand life science"). We conducted the content analysis with the remaining 688 items (range per state: 1 to 44 items).

Coding Scheme

To capture the abstraction level of science facts, we distinguished between concrete and abstract facts. Specifically, *concrete* facts were defined as those that are readily perceivable, without having to connect any pieces of information. Examples of concrete facts are visible physical properties (color, size, material) or obvious events (e.g., sinking). We also included facts that could be observed directly (e.g., sound, light, shadow), as long as there was no explicit requirement to understand the source of those phenomena. References to vocabulary, rules, or functions were also treated as concrete, since this information merely needs to be memorized.

Abstract facts, on the other hand, refer to information that is hidden and thus requires some mental effort to access. Consider, for example, the construct of "family." For a group to be family, there have to be unique relations among the members of the group. These relations cannot be reduced to a physical property or a salient event. Instead, individual pieces of information must be integrated into a coherent whole to arrive at the construct of "family."

For abstract facts, we distinguished between *relations, patterns, groups,* and *forces* (see Appendix A.4 for detailed information about these codes). The *relations* code captures connections between entities, whether the connection is causal ("effect," "impact," "control"), correlational ("interaction," "heredity"), or based on dependency (e.g., "protect," "preserve"). The *patterns* code captures events that unfold over time (e.g., "life cycle," "transformation," "motion"). The *groups* code captures distinctions between entities that are based on hidden characteristics or traits ("living vs. nonliving things"). And the *forces* code captures references to causal properties (e.g., "gravity," "magnetism," "buoyancy," "energy").

Note that the abstract categories of *relations, patterns, groups,* and *forces* are interrelated. For example, all relations are also patterns, and all forces are also relations. To distinguish codes consistently, we chose to base our coding scheme on individual words or phrases. For example, the item "describe the effects of forces in nature" received the code of *relations* (because of its reference to cause-effect relations) as well as the code of *forces* (because it invoked the term "force").

Note also that concrete terms were sometimes nested within abstract phrases. For example, the phrase "the effects of an action on an object" consists of both an abstract code (a causal relation) and a concrete code ("an object"). In cases like this, we coded both the abstract and the concrete part of the phrase. As a result, some items contained both concrete and abstract terms (vs. items that consisted entirely of concrete terms or items that consisted entirely of abstract terms).

Coding Procedure

Coding followed the same iterative process that was used in Study 1. We first drafted initial definitions of codes and then refined them through subsequent rounds of coding and discussion. Specifically, we identified all the fact phrases and determined whether each one was concrete or abstract (and, in the latter case, whether it falls into the category of *relations, patterns, groups,* or *forces*). In each round, two independent coders went through the items and coded them, then came together to discuss the disagreements and refine the definitions of the codes.

While all disagreements could be resolved during the aforementioned iterative process, one item provoked repeated discussion: "Recognize that everything is made of matter." Going by majority decision, this item was ultimately coded as *groups*, the argument being that the item was indicative of an underlying trait (i.e., everything has the hidden characteristic of matter).

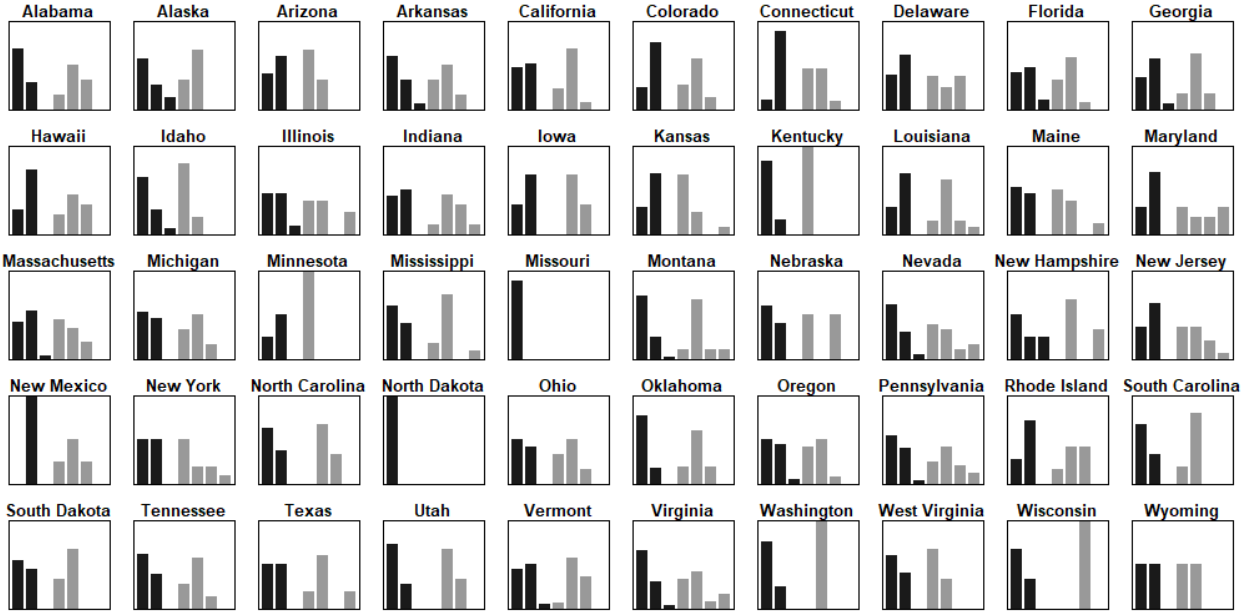
Results

Results are presented in three sections: The first section focuses on the variability among state standards. We then consider the broad contrast among items that contained only concrete terms, concrete and abstract terms, or only abstract terms. Of interest was the relative prevalence of each type of item (*concrete-only*, *concrete-and-abstract*, *abstract-only*) as a function of the domain of science. Finally, we look more specifically at the four types of abstract facts (*relations, patterns, groups, forces*) and explore their relative prevalence in each domain of science.

Differences Among States

Similar to Study 1, there were several differences across state standards (see Appendix B.2 for the number of fact items and terms by state). For example, while some standards included information about science facts for virtually all of their items (20%), others provided far fewer facts. There was even a difference in the number of facts per specified item, ranging from one to four facts per item. State standards also differed in the domain of science that was covered. For example, while some standards did not include any life-science items (16%), other standards featured them prominently. We found similar variability with physical science*:* While one state standard was comprised exclusively of physical-science items, two standards had none at all.

We also found differences in the degree to which the standards recommended abstract versus concrete facts (see Figure 5 for the profiles of each state standard, separated by types of items and types of facts). For example, two state standards consisted entirely of concrete items. And, while abstract content presumably builds upon concrete foundations, 38% of state standards nevertheless featured at least one exclusively abstract item. And, concerning the different types of abstract facts (*relations, patterns, groups,* *forces*), many standards featured at least three types of abstraction (46%). Eight standards listed all four types of abstraction, while four only had one primary abstraction code.



Note. The dark bars show the proportion of each type of item (*concrete-only, concrete-and-abstract, abstract-only*). The light bars show the proportion of each type of abstract fact term (*relations, patterns, groups, forces*).

Figure 5. Proportion of types of items and terms by state

Broad Contrast Among Different Items

Recall that an item could have concrete terms, abstract terms, or a combination of both (e.g., when concrete terms were nested within abstract terms). Table 2 displays the relative prevalence of each of these types of items. Results show that only 2% of the items had exclusively abstract content. This holds for the individual domains of science as well: The prevalence of abstract-only items ranged from 0% (multiple sciences) to 4% (earth/space science; other science).

At the same time, when considering whether items had at least some abstraction (i.e., abstract-only or concrete-and-abstract), the proportion of items with at least some abstract content is sizable (47% across domains). Using Generalized Linear Mixed-Effects Models (GLMMs) (Hox, 2010) to compare relative frequencies, we found that the presence of abstract content did not differ across science domains, $D(4) = 5.00$, $p = .287$. Almost half of the items in life science (45%), physical science (50%), and earth/space science (49%) featured abstract facts.

Specific contrast among abstract codes

Table 2 also shows the relative prevalence of the different types of abstract codes (*relations, patterns, groups, forces*). The *forces* code was the least common across the domains of science, found in only 6% of abstract fact phrases. Even within physical science, arguably the natural home of force-related concepts, only 14% of fact phrases referred to forces. The *groups* code was also relatively uncommon, occurring in only 16% of the abstract fact phrases. Here, we found a difference in proportion by domain, $D(4) = 32.35$, $p < .001$, with life science being the domain with the most *groups* codes, post-hoc Wald test $Ws(1) > 4.75$, $ps < .029$. A typical example of this code was to "categorize common living things as either plants or animals."

Table 2. Proportion of types of items and types of abstract terms within each science domain

Level of Abstraction	Domain of Science					
	Life	Physical	Earth/Space	Other	Multiple	Total
Types of Items						
Concrete Only	55%	50%	51%	62%	47%	52%
Concrete & Abstract	44%	46%	45%	32%	51%	44%

Abstract Only	<1%	3%	4%	4%	-	2%
Types of Abstract Terms						
Relations	25%	32%	13%	83%	33%	31%
Patterns	46%	46%	76%	14%	28%	47%
Groups	28%	8%	10%	3%	37%	16%
Forces	1%	14%	-	-	2%	6%

Note. Percentages were calculated within their respective domains. Deviations from totals of 100% stem from rounding errors.

The *patterns* code was more prevalent than that of *forces* and *groups*, found in 47% of the fact terms. Here too, we found a difference in proportion by domain, $D(4) = 42.02$, $p < .001$, with earth/space science being the domain with the most *patterns* codes (76%), Wald test $Ws(1) > 3.58$, $ps < .058$. One of the most common *patterns* constructs in this domain were cycles, such as the day/night and water cycles. Patterns were also common in the domains of life science and physical science, found in 47% of the abstract fact terms of each of these domains. Typical examples were growth over time (life science) and the motion of objects (physical science).

Finally, the *relations* code was of intermediate prevalence, found in 31% of the fact phrases across domains. Finding a difference by domain, $D(4) = 25.36$, $p < .001$, *relations* were most common in the physical-science domain (32%). For this domain, the most common *relations* construct was cause and effect (e.g., "cause and effect of pushing/pulling objects"). In contrast, *relations* were less common in the life-science domain (25%), $W(1) = 5.78$, $p = .016$, and even rarer in the earth/space science domain (13%), $W(1) = 10.45$, $p = .001$. Typical examples were interactions between living things and their environments (life science) and how weather relates to seasons (earth/space science).

Discussion

Are preschool children expected to attend to and learn about science facts that require abstract thought? Like with abstract inquiry in Study 1, we found that this is indeed the case: About half of the items assessed in the content analysis featured at least one abstract fact, regardless of science domain. Specifically, preschool children are expected to pay attention to patterns that unfold over time, most notably in the domain of earth/space science. They are also expected to pay attention to relations, for example when asked to think about humans and nature. They were even expected to pay attention to forces, though to a lesser degree than to relations or patterns.

General Discussion

Our work was motivated by a noticeable dip in the amount of scholarly work on early science learning. While we cannot claim to know the sources of this decline, there are several points of tension in the field that might hamper progress. In fact, there appear to be unresolved questions regarding whether young children are able to learn science constructs at all. Our paper was designed to address unresolved issues by looking more specifically at the difficulty level of the science constructs recommended for preschool.

Our results show that recommended science constructs vary widely in learning difficulty. Regarding inquiry, for example, most educational standards recommend something as simple as observing the surroundings with one's own senses. At the same time, they also recommend something as sophisticated as formulating and testing explicit hypotheses. Even the activity of generating explanations is common in the educational standards. A similar pattern emerges with science facts: While many standards recommend knowing something as obvious as the names of body parts, they also recommend knowing about patterns that evolve over time, such as the lifecycles of animals. Thus, preschool science is neither difficult nor easy: It is both.

Given the variability in learning difficulty of recommended science concepts, a conclusive "yes-or-no" answer to the question of whether young children can learn science is perhaps not sensible: Young children are cognitively ready to comprehend some, but not all, science constructs. That is to say, before an answer can be provided about classroom organization, teacher preparation, or pedagogy, more information about the difficulty level of the desired science construct is needed. When science constructs are concrete, young children can learn them spontaneously, merely via play (e.g., observing the surrounding). In contrast, when science constructs are abstract (e.g., making predictions; understanding the impact of gravity on objects), spontaneous play in the everyday surrounding is no longer enough to promote learning.

Still, learning about abstract science constructs is possible for young children. Research has shown that preschoolers can reason abstractly, such as when testing a hypothesis or reaching a conclusion (Bonawitz et al., 2011; French, 2004; Sobel & Legare, 2014; Sodian et al., 1991; Trundle & Smith, 2017). To be able to do this, however, children need exposure to a setting that highlights otherwise hidden links. For example, in order to formulate and test a hypothesis, the relevant variables need to be more salient than irrelevant variables (Kloos et al., 2019). In a typical preschool classroom, such order is unlikely to be present (e.g., Fisher et al., 2013; Kirschner et al., 2006). Thus, learning about abstract science constructs requires a change in the everyday preschool setting.

Research has indeed identified some strategies that might be helpful for acclimating young children to abstract science concepts. For example, prompting children to document their observations and talk about observed similarities and differences is a feasible and effective strategy to highlight what might otherwise remain hidden (e.g., Brenneman & Louro, 2008; Fleer, 1991; Fleer & Beasley, 1991). Similarly, the use of schematic representations such as concept maps or conceptual models can help young children see how entities or events are related (e.g., Gobert & Buckley, 2000; Hunter et al., 2008; Kenyon et al., 2008; Novak, 2010; Wiser & Smith, 2008). Incidentally, we found that the educational standards only rarely recommended the use of tools to visualize otherwise hidden relations.

Regarding preschool teachers' apprehension about incorporating science into the general curriculum, our findings highlight the importance of specifying the degree of difficulty of the chosen science constructs. Vaguely phrased science items could give practitioners some leeway in their curriculum choices. For example, teachers who are unsure about science pedagogy could focus on science constructs that can be learned spontaneously during children's play (i.e., concrete science constructs). At the same time, the lack of specificity is likely to put a heavy burden on teachers to come up with ways of organizing their science curricula. The solution is to work out a clear definition of science and recommend a sensible ordering from lower- to higher-abstraction constructs—which is currently missing from the educational standards.

Conclusion

Even though the field of early science learning has enjoyed increased attention over the decades, fundamental disagreements remain, such as about whether young children are capable of learning science. Our findings put important constraints in place to address this disagreement. Specifically, we found that scientific inquiry and scientific facts recommended at the preschool level vary considerably in difficulty. This suggests that the question of whether children can learn science depends on how difficult the particular science construct is. Young children might be able to easily learn salient science constructs from exposure alone. For more hidden science constructs, however, a more intentional effort might be needed to support preschoolers' learning.

Our findings also highlight an important gap in the field of early science learning: that there is no universally accepted definition of science at the preschool level. For example, while state recommendations largely agree on including both concrete and abstract science constructs, there are numerous differences among the existing recommendations. Without a clear definition of early science, research on science learning is necessarily confined to the idiosyncratic definitions adopted by each research team. In turn, this curtails transferability to the preschool classroom and, thus, has only limited practical relevance for those who operate under a different definition of science. Before early science education can be successful, then, it might first be necessary to adopt a consistent definition of science.

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Adherence to ethical concerns

The research reported here does not involve human subjects. The basis for the research was the analysis of records that are publicly available (educational standards).

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Appendix A: Coding Schemes

Appendix A.1 Explanation of Codes for Non-Science Items

Codes	Words and Phrases	Example
Engineering	Broadly: finding solutions, fixing something broken, creating a non-scientific model Specifically: solves problems, builds a structure, use tools in play, develop procedures, invent	"Construct a device to protect from the sun" "Solve problems by designing or using tools"
Math	Broadly: counting, using numbers, doing math without connection to science Specifically: use numbers, use quantities, uses mathematical thinking, counts	"Uses number to represent quantity" "When counting, assigns number to each item"
Language Arts	Broadly: reading, writing, or speaking with a focus on the process of language proficiency rather than science Specifically: makes signs, uses letter-like symbols, writes messages, listens to stories, tells stories, repeats words	"Talk about ways to be safe" "Repeat new words"
Personal Growth	Broadly: following the rules, learning norms, showing respect, developing traits Specifically: showing respect, follows rules, asks for help, invites peers, develops personal interest, shows surprise	"Demonstrate respect" "Follows directions"
Caring for Others	Broadly: referred to volunteering time, assisting, helping Specifically: Take care of, participate in care, express concern, is considerate	"Care for plants and animals in the classroom" "Participate in activities that help to care for the environment"

Appendix A.2 *Explanation of Codes for Inquiry Terms (Study 1)*

Codes	Words and Phrases	Examples
Unspecified		
	become familiar; determine; develop a sense; develop an awareness; engage in activities; explore; find out; inquiry; interact with; investigate; know; learn; look for answers; manipulate; pursue questions; reason; reflect; seek information; think about; try things out; understand	"Explores what a variety of living organisms need to live and grow (e.g., water, nutrients, environment)" "Investigates concepts of structures."
Low Degree of Abstraction (Levels 1, 2)		
Level 1: Observe-without-Tools	collect data; collect information; discover; examine; gather information; make observations; manipulate; notice; observe; sensory exploration; use senses	"Observes the characteristics and movement of the sun, moon, stars, and clouds" "Makes simple observations of the characteristics, movement, and seasonal changes of the sun, moon, stars, and clouds."
Level 2: Observe-with-Tools	explore with tools; gather information with tools; investigate with tools; measure; use books	"Use tools to explore the properties and characteristics of objects" "Uses simple tools for exploration and investigation."
Medium Degree of Abstraction (Levels 3, 4, 5)		
Level 3: Communicate-without-Tools	answer questions; confirm (observations); count; define; demonstrate (awareness, knowledge); describe; discuss; display data; document observations; draw; evaluate; give examples; identify; indicate (awareness, knowledge); infer; interpret; know vocabulary; label; name; offer critique; present; recall; recognize; record (data, information); represent; retell; share (explanations, findings, ideas); show understanding; summarize observations; take pictures; talk; use evidence	"Begins to use scientific vocabulary" "Observes and describes characteristics, basic needs, and simple life cycles of living things."
Level 4: Communicate-with-Tools	create maps; graph; use charts; use models; use tally sheets	"Collect, describe, and record information through discussions, drawings, maps, and charts." "Record observations using simple visual tools."
Level 5: Ask-Questions	be curious; demonstrate interest; express wonder; generate questions; show curiosity; show interest	"Exhibits curiosity about objects, living things, and other natural events in the environment." "Asks and responds to questions about relationships of objects, living things, and events in the natural environment."
High Degree of Abstraction (Level 6, 7, 8, 9)		
Level 6: Compare-Contrast	analyze data; categorize; classify; differentiate; discriminate; distinguish; match something with something else; order; organize; sort	"Compares and categorizes solids and liquids based on their physical properties" "Compares baby and adult animals and recognizes similarities (e.g., matches adult stuffed animals with their baby in a play setting)"
Level 7: Predict	anticipate; formulate hypothesis; make guesses; make predictions; predict changes	"Make predictions about changes in materials or objects based on past experience." "Describe and anticipate weather changes."

Level 8: Test-a-Prediction	check predictions; experimentation (engage in, explore through); participate in experiments; test hypotheses; verify predictions	“Test a variety of materials and configurations to design an end product.” “Adjusts their approach if results are different than expected and continues testing.”
Level 9: Explain	conclude (draw, formulate, make conclusions); explain; form explanations; generalize; generate explanations	“Constructs theories to explain their investigations.” “Develops increasingly detailed explanations of their ideas and reasons”

Appendix A.3 Explanation of Codes for Domains of Science (Study 2)

Codes	Words and Phrases	Examples
Life Science		
	Broadly: biology, organism(s), life Specifically: plants, animals, growth, senses, living objects, effect on living things (e.g., of the weather, habitats, environment, seasons)	"Uses senses to observe and describe the properties of familiar plants and animals" "Ask and answer questions about changes in the appearance, behavior, and habitats of living things."
Physical Science		
	Broadly: physics, chemistry. Specifically: objects, motion, sound, light, vibrations, forces, magnetism, materials, matter, circumstances, physical models, physical structures, speed, fast/slow, heating/cooling, melting/freezing, light as energy, light variations, shadows, sinking, floating, temperature, things, states of matter	"Investigates and describes different types or speeds of motion" "Use objects to effect motion (e.g. build a ramp with blocks so the car goes faster)"
Earth/Space Science		
	Broadly: astronomy, meteorology, geology Specifically: earth materials, objects in the sky, sun, moon, stars, water cycle, rock cycle, day/night (cycles), natural objects, natural resources, materials in the environment, changes in the environment, non-living things in the environment (e.g., rocks, minerals, water), seasons, weather, impact of weather on the environment	"Describe how the Earth's surface is made up of different materials" "Observe, describe, and discuss the characteristics of the sun, moon, stars, and sky"
Other Science		
	Broadly: technology, social science, methodology, complex systems, environmentalism. Specifically: effects on daily life (e.g., of the weather), effect of own actions, family, culture, digital media/devices, tools, scientific principles/process, caring for the planet, conservation, recycle/reuse, climate change, environmental concerns, pollution, human impact on earth/weather/seasons, uses of water, complex concepts, guidelines, day/night activities, human use of materials/resources/etc.	"Explains why a simple machine is appropriate for a particular task" "Explore and use simple tools and machines."
Multiple Sciences		
	Combinations (2 or more) of the above categories (Life, Physical, Earth/Space, or Other)	"Explore concepts and information about the physical, earth, and life sciences" "Discriminate between living organisms and non-living objects"
Unclear domain of science		
	World, data, information, environment, nature, events	"Ask questions to find out more about the natural world." "Displays and interprets data."

Appendix A.4 Explanation of Codes for Facts (Study 2)

Codes	Words and Phrases	Examples
Concrete		
	items; objects; materials; activities; resources; events; actions; characteristics; properties; features accessible via senses (visual, auditory, etc.); need; function; purpose; rules; vocabulary; tools (e.g., microscope, computer); reuse/recycle; weather; seasons; habitat; light/shadow; sink/float; ramps; speed (fast, slow); pushing/pulling	L: "Identify and describe common animals and insects." P: "Identify materials that make up objects." E/S: "Identify common earth materials and landforms." O: "Describe typical day and night activities." M: "Describes objects and living things in increasing detail."
Abstract		
Relations	affect; impact; interact; influence; control; cause/effect; why X happens; result of; respond to; generate; depend on; provide for; take care of; protect; preserve; system; family; heredity; offspring; density	L: "Asks questions about the relationship between two things (e.g., Why do you think some animals sleep in the day?)." P: "Investigate different sounds made by different objects and different materials." E/S: "Demonstrates, through observation and investigation, an understanding that human action impacts the earth" O: "Identify how weather affects daily life." M: "Asks and responds to questions about relationships of objects, living things, and events in the natural environment."
Patterns	patterns; changes; cycles (e.g., rock, water); stages; sequence; routine; growth; moving/motion; stability; transformation (e.g., solids to liquids); melting/freezing; heating/cooling; dissolving; polluting	L: "Demonstrates an understanding that living things change over time in size and other capacities as they grow". P: "Explore and describe in greater detail changes in objects and materials." E/S: "Uses senses and tools (including technology) to observe, describe, discuss and generate questions about changes in weather over time" O: "Understands how actions people take may change the environment" M: "Show an awareness of changes that occur in oneself and the environment."
Groups	groups; categories; kinds of; types of; similarities/differences among groups (e.g., mammals; species; age group; living/nonliving); X as Y (e.g., "wetland as an ecosystem"); X vs. Y; X to Y (young to old); X from Y; models.	L: "Compares baby and adult animals and recognizes similarities." P: "Explore different kinds of matter and describe by observing properties." E/S: "Identify various types of moving water" O: "Describe the types of clothing needed for different seasons." M: "Begins to describe the similarities, differences and relationships between objects, living things and natural events."
Forces	force; inertia; friction; buoyancy; magnetism; electricity; gravity; falling without support; vibrations making a sound; energy; light (when a source of energy); heat (when a source of energy)	P: "Explore the effect of force on objects in and outside the early childhood environment." P: "Describes and compares the effects of common forces on objects and the impact of gravity, magnetism and mechanical

		forces.”
General Science		
	general statements about a domain of science; scientific principle; scientific process	L: “Ask questions and conduct investigations to understand life science.” E/S: “The child investigates and observes the basic concepts of the Earth” O: “With prompting and support, use scientific vocabulary words to describe steps in the scientific process” M: “Pose questions about the physical and natural environment.”

Note. The acronyms pertain to the various domains of science (L: life science, P: physical science, E/S: earth/space science, O: other science, M: multiple sciences).

Appendix B: Number of Items and Terms per State

Appendix B.1 Number of Inquiry Items and Terms (Study 1)

	Non-Science Items						Inquiry Terms	
State (Publication Year)	E	M	LA	PG	CfO	Science Items	Unspecified Items	Specified Terms
Alabama (2012)	1			1		17	2	26
Alaska (2007)					1	14	2	17
Arizona (2018)				1		14	1	14
Arkansas (2016)	1			2		24	4	31
California (2012)						25	7	32
Colorado (2011)						11	1	22
Connecticut (2014)						15	3	15
Delaware (2010)				1		20	4	27
Florida (2019)	2			1		26	5	30
Georgia (2019)	1					17	7	21
Hawaii (2014)						11	3	16
Idaho (2014)	1	5	12	15		31	6	41
Illinois (2013)		1		2		18	5	27
Indiana (2014)		2				20	1	23
Iowa (2017)						6	4	3
Kansas (2014)						13	3	15
Kentucky (2010)						14	0	18
Louisiana (2013)				1	1	21	3	30
Maine (2015)	6		1			19	3	31
Maryland (2010)	1		1			13	2	23
Massachusetts (2010)						30	7	35
Michigan (2013)						17	2	25
Minnesota (2014)	3			2		15	3	14
Mississippi (2018)	3					28	8	32
Missouri (2013)	3					9	6	3
Montana (2014)	3			3		37	10	39
Nebraska (2018)						13	3	12
Nevada (2010)			1			46	28	25
New Hampshire (2011)						4	1	3

New Jersey (2014)				1		21	10	37
New Mexico (2017)						10	1	12
New York (2019)		1				18	5	17
North Carolina (2013)					2	19	1	32
North Dakota (2018)			1			4		4
Ohio (2019)						21	8	19
Oklahoma (2016)	1		1		3	38	19	33
Oregon (2016)					1	27	8	31
Pennsylvania (2014)				4		44	7	52
Rhode Island (2013)						19	3	23
South Carolina (2017)	1			1	3	19	2	37
South Dakota (2019)	3		1		4	30	3	42
Tennessee (2019)						17	2	28
Texas (2015)					1	10	6	18
Utah (2013)	1					14	2	13
Vermont (2015)	6				1	22	6	22
Virginia (2013)						34	3	40
Washington (2012)			1		2	9	2	11
West Virginia (2019)						11	5	10
Wisconsin (2013)	2			1		15	4	23
Wyoming (2009)						9	5	14
Total	40	6	19	34	19	959	236	1168

Note. Items differed in whether they pertain to science (*science items*) or not (*non-science items*). Non-science items could be about engineering (E), math (M), language arts (LA), personal growth (PG), or caring for others (CfO). Appendix A.1 provides detailed information about the non-science items were defined. For science items, the abstraction level of their inquiry terms was coded. Inquiry terms could be *unspecified* (i.e., too vague to fit a single abstraction code), or they could be *specified* (i.e., precise enough for an abstract code). Items with only unspecified inquiry terms were referred to as unspecified items.

Appendix B.2 Number of Fact Items and Terms (Study 2)

State	Items without Domain	Items with Domains					Fact Terms				
		L	P	E/S	M	O	Co	R	P	G	F
Alabama	4	3	5	4		1	9	1	3	2	
Alaska	7	2	2	3			4	1	2		
Arizona	9				5		2	2	1		
Arkansas	9	5	3	1		6	9	2	3	1	
California	4	6	8	3	2	2	10	3	9	1	
Colorado	3	3	4	1			2	2	4	1	
Connecticut	6	3	4		1	1	1	5	5	1	
Delaware	7	4	2	3	2	2	5	3	2	3	
Florida	7	6	5	4	2	2	8	4	7	1	
Georgia	3	3	5	4	1	1	5	2	7	2	
Hawaii		2	5	2	1	1	3	2	4	3	
Idaho	17		7	2	2*	2	8	4	1		
Illinois	7	2	4	2	1	2	5	3	3		2
Indiana	4	2*	6	4	1	2	7	1	4	3	1
Iowa	3		1		2		1		2	1	
Kansas		3	2	1	2	5	4	8	3		1
Kentucky	8		6				5	1			
Louisiana	5	5	3	3	2	2*	4	2	8	2	1
Maine	4	5	5	3		2	8	4	3		1
Maryland	3	2	7	1			3	3	2	2	3
Massachusetts	1	9	9	4	4	3	12	9	7	4	
Michigan	4	4	2	4	3		7	2	3	1	
Minnesota	11		1			2*	1	2			
Mississippi	3	11	7	3	4		15	2	8		1
Missouri		3	2*	3			8				
Montana	5	7	11	12	2	*	22	1	6	1	1
Nebraska	8	1	2		2		3	1		1	
Nevada	7	15	13	6	2	2*	24	7	6	2	3
New Hampshire		1	1	1		1	2		2		1

New Jersey	2	5	7	1	6		7	5	5	3	1
New Mexico	6			4				1	2	1	
New York		4	7	3	3	1	9	5	2	2	1
North Carolina	11	1	5	1		1	5		2	1	
North Dakota	3				1		1				
Ohio	9	5	3	3	*		6	2	3	1	
Oklahoma	11	5	11	6*	1	3	21	1	3	1	
Oregon	7	6	8	3	2	1	10	5	6	1	
Pennsylvania		12	7	9	4	12	24	6	10	5	3
Rhode Island	5	6	5		2	1	4	2	5	5	
South Carolina	7	2	7	2	1		8	1	4		
South Dakota	10	4	9	3	2	2	11	4	8		
Tennessee	4	3	4	2	2	2	8	2	4	1	
Texas		3	4	3			5	1	3		1
Utah	3	4	3	3	1		8		2	1	
Vermont	2	6	8	5	1		9	1	8	5	
Virginia	5	4	10	5	2	8	19	4	5	1	2
Washington	5	1	1	2			3		1		
West Virginia	6	1	1	1	1	2	3	2	1		
Wisconsin	12		1		2		2			1	
Wyoming	5	1	3				2	1	1		
Total	262	181	237	129	74	76	362	120	180	61	23

Note. Items differed in whether they could be attributed to a domain of science (*items with domains*) or not (*items without domains*). Domains refer to life science (L), physical science (P), earth/space science (E/S), other science (O), and multiple sciences (M). Appendix A.3 provides detailed information about how the domains of science were defined. The fact terms differ in whether they were concrete only (Co), a relation (R), a pattern (P), a group (G), or a force (F).
*reflects the presence of any additional items not included in the count that were too broad to receive a code for their abstraction level (e.g., "life science").