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Research Article

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

Amanda S. Haber[1], Hannah Puttre[2], Maliki E. Ghossainy[3], Kathleen H. Corriveau[4]

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,

[1] Boston University, Doctoral Student, Wheelock College of Education and Human Development, Boston, United States, email: haber317@bu.edu, ORCID: https://orcid.org/0000-0001-9578-3826

[2] Boston University, Doctoral Student, Wheelock College of Education and Human Development, Boston, United States, email: hputtre@bu.edu, ORCID: https://orcid.org/0000-0002-8366-3170

[3] Boston University, Senior Research Scientist, Wheelock College of Education and Human Development, Boston, United States, email: malikig@bu.edu, ORCID: https://orcid.org/0000-0002-4644-215X

[4] Boston University, Professor, Wheelock College of Education and Human Development, Boston, United States, email: kcorriv@bu.edu, ORCID: https://orcid.org/0000-0002-6354-1141

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

Delivery and Content	Speaker	
	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; β = 1.10, $p < .01$) and 3 (Day 7 to Day 8; β = .89, $p < .01$; Day 8 to Day 9, β = .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).

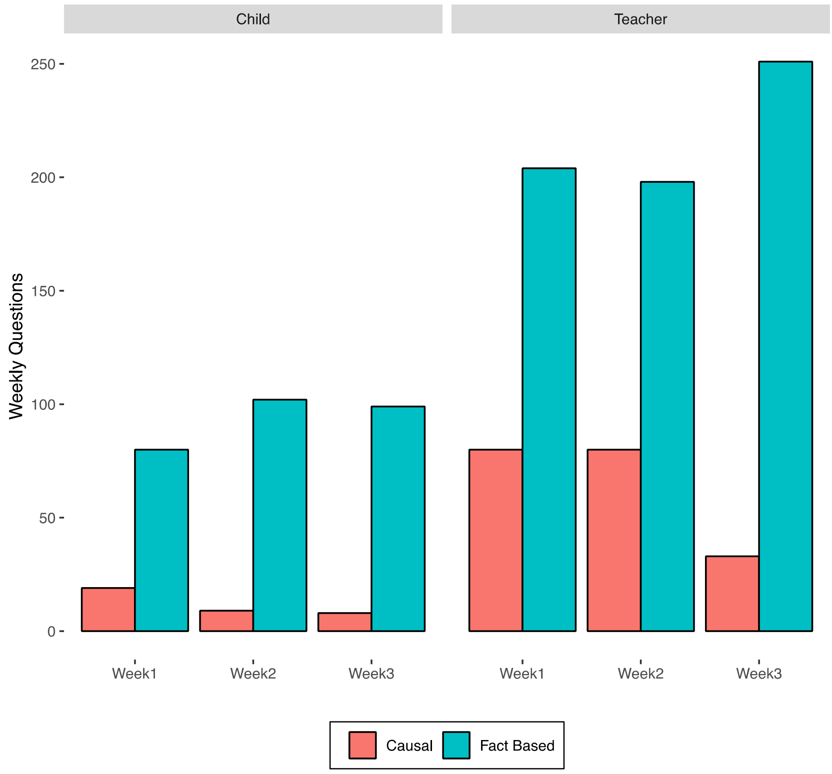

Figure 1. Frequency of information-seeking (causal and fact-based) questions by Speaker and Week during the extended inquiry.

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, $\beta = .66$, $p < 0.01$), and Week 2 (Day 5 to Day 6: $\beta = .57$, $p < 0.01$) and significantly decreased in Week 3 (Day 8 to Day 9, $\beta = -0.49$, $p < 0.01$). 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.

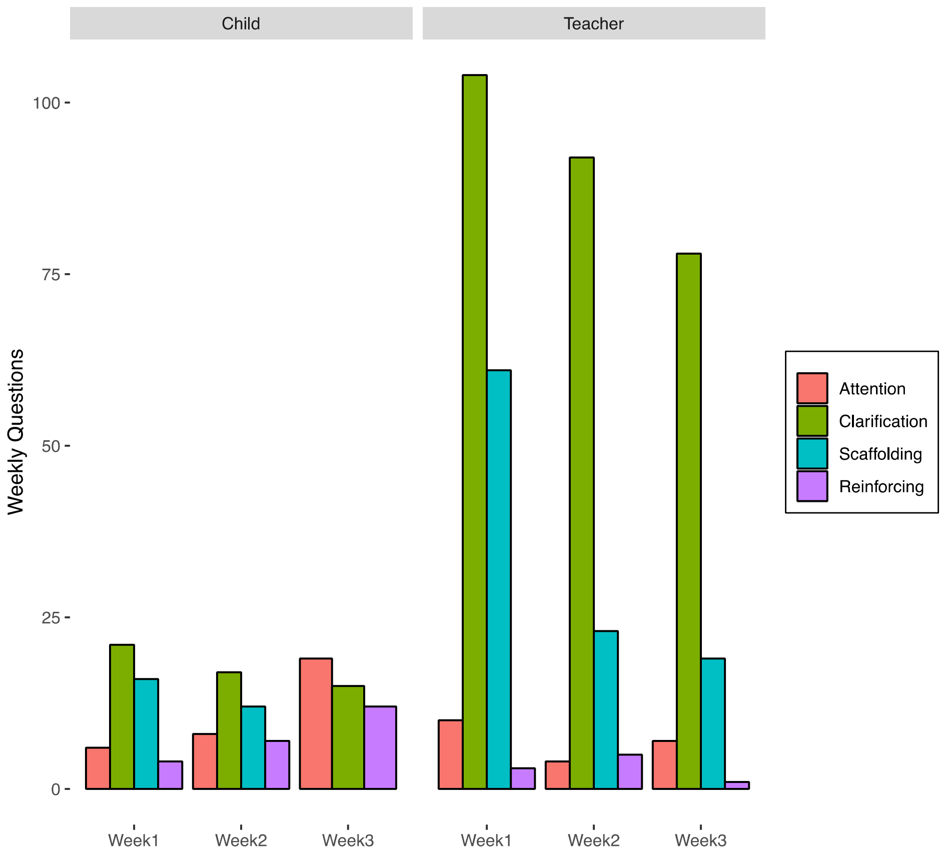

Figure 2. Frequency of noninformation-seeking (attention, clarification, scaffolding and reinforcing) questions by Speaker and Week during the extended inquiry.

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, $p < 0.001$).

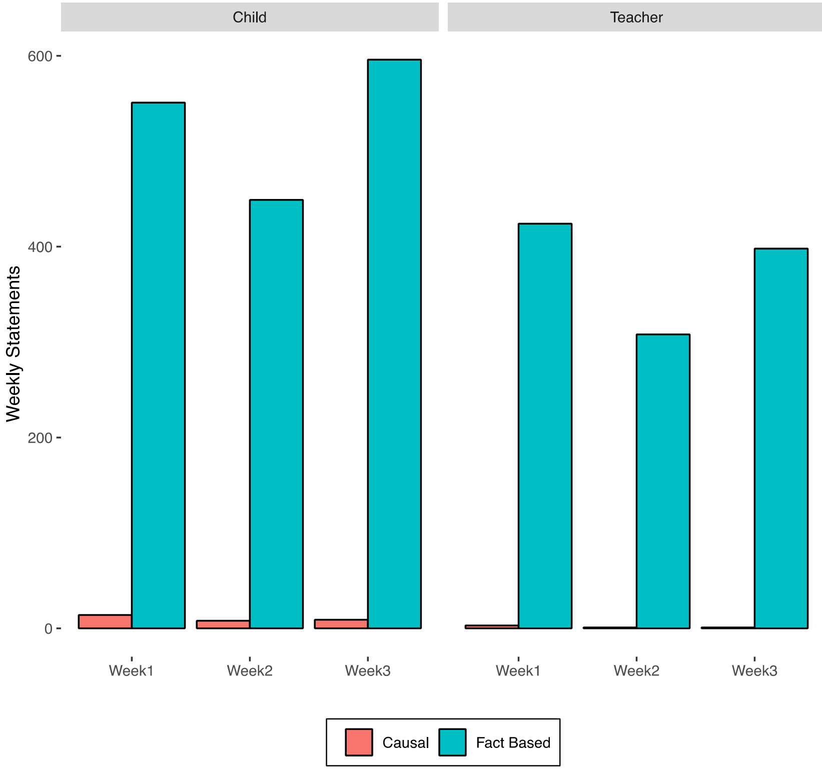

Figure 3. Frequency of informational (causal and fact-based) statements by Speaker and Week during the extended inquiry.

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.

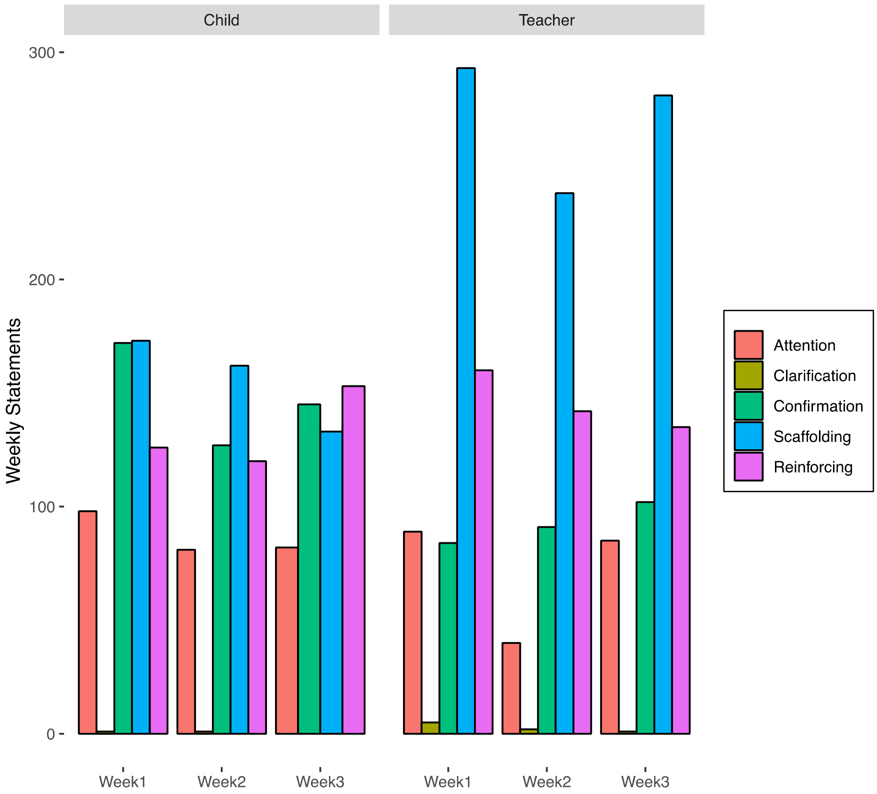

Figure 4. Frequency of noninformational (attention, clarification, confirmation, scaffolding and reinforcing) statements by Speaker and Week during the extended inquiry.

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 (β = -0.25, $p < 0.05$), but increased again from Week 2 to Week 3 (β = 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 (β = -0.22, $p < 0.001$), but a significant increase from Week 2 to 3 (β = 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 (β = -0.24, $p < 0.01$), but significantly increased from Week 2 to 3 (β = 0.37, $p < 0.05$). Similarly, for children, there was a significant decrease in responses from Week 1 to 2 (β = -0.18, $p < 0.05$), but a significant increase from Week 2 to 3 (β = 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 ($\beta = 1.56$, $p < 0.01$). Furthermore, responses significantly decreased from Weeks 1 to 2 ($\beta = 0.23$, $p < 0.01$). 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 ($\beta = -0.28$, $p < 0.001$). 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 ($\beta = -0.43$, $p < 0.01$) and a significant increase from Week 2 to 3 ($\beta = 0.33$, $p < .01$). 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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Authors' contributions: KHC designed the study. ASH and KHC collected the data. ASH and HP transcribed and coded the data. MEG analyzed the data, created the graphs, and contributed to the results section. ASH and HP wrote the manuscript. MEG and KHC provided feedback on manuscript drafts. All authors approved the final manuscript draft.

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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