Science
Education

SCIENCE LEARNING IN EVERYDAY LIFE

Designing for Learning Conversations: How Parents Support Children's Science Learning Within an Immersive Simulation

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Received 4 August 2014; revised 25 November 2015; accepted 20 January 2016
DOI 10.1002/sce.21228
Published online in Wiley Online Library (wileyonlinelibrary.com).

ABSTRACT: This research investigates the social learning affordances of a room-sized, immersive, and interactive augmented reality simulation environment designed to support children's understanding of basic physics concepts in a science center. Conversations between 97 parent–child pairs were analyzed in relation to categories of talk through which children's activities are structured, and their physical and perceptual experiences are related to scientific content knowledge. We provide a detailed account of how parents guide children's scientific reasoning in this novel learning environment, such as by structuring the exploration, and emphasizing perceptual observations as evidence and data. We argue that this particular type of interactive environment affords activities that support learning of complex ideas in science, empowering parents to provide support to the children's perceptual focus and physical engagement. Our findings contrast with studies on high-interactive immersive environments that have typically shown that children tend to isolate themselves from their social surroundings. Mixed-reality environments, in contrast, appear to support significant social interaction, while still offering children playful and engaging experiences.
 Sci Ed 1–26, 2016

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INTRODUCTION

Out-of-school informal learning experiences play an increasingly prominent role in children's science learning (Falk & Dierking, 2000; National Research Council [NRC], 2009). A particularly important development in support of this role is the use of innovative digital technology in science centers and museums. These technologies, such as augmented reality or mobile technology, offer opportunities to produce exhibits and devices that are highly interactive and engaging, allowing for new physical and sensory experiences that can enhance children's learning (e.g., Falk & Dierking, 2008; Wishart & Triggs, 2010; Yoon, Elinich, Wang, Steinmeier, & Van Schooneveld, 2012).

While the use of such technologies is often justified in terms of visitor interest and engagement (Sandifer, 2003), increasingly they are designed intentionally to structure activities for children's learning of scientific reasoning and to support meaningful parent–child dialogues around science concepts (Heath & vom Lehn, 2009; Yoon, Elinich, Wang, Steinmeier, & Tucker, 2011). The basis of this trend is the acknowledgment that parents provide a vital role in the development of children's scientific reasoning and understanding of science concepts through social interaction in informal settings. Kuhn (1993) suggests that scientific thinking is not exclusive to formal "sites of science," but can be found in informal everyday interaction, especially in conversations between parents and children. The recent NRC report presents a model of science learning that includes as a critical component the engagement with scientific thinking and discourse in informal settings (NRC, 2009), and there is growing evidence that family conversations around interactive and hands-on informal learning experiences are a key component of children's learning (Ash, 2003; Crowley et al., 2001a; Leinhardt & Knutson, 2004; Zimmerman, Reeve, & Bell, 2010). An important research question emerging from these trends is how parents and children interact with emerging digital technologies that are physically immersive, and how to design such technology in support of conversations conducive for science learning.

In this paper, we examine how a particular large-scale, immersive, and interactive simulation platform was used by parents to provide support for children's practice of scientific reasoning and their understanding of embodied and sensory experiences in accordance with the physics of how objects move in space. The simulation, called *MEteor* (Lindgren, Tscholl, Wang, & Johnson, 2016) is a room-sized augmented reality[1] environment designed to help children obtain an intuitive understanding of force and motion in a celestial context. In *MEteor*, children engage physically with virtual objects, enacting and developing their knowledge through a physical performance. Parents, located at one side of the simulation, may support the child with explanations drawing on concepts of the physics of force and motion of objects in space, and with strategies to successfully complete the simulation tasks.

Immersive, performance-oriented exhibits that are physically interactive are being installed at science centers with increasing frequency. The potential to produce complex science phenomena in a way that is engaging for children is a significant reason for this trend. Another apparent motivation is the desire to improve on interactive museum experiences of the past that have had mixed results in terms of whether parents support a child's learning (cf. Gutwill & Allen, 2010). *MEteor* leverages the capabilities of augmented reality technology to distribute tasks and knowledge so as to instigate grounded and productive parent–child discussions. In *MEetor*, children engage playfully with virtual objects

[1] Augmented reality (AR) is on the spectrum of mixed reality (MR) technologies (Milgram & Kishino, 1994) where digital elements are in some way integrated with real-world elements within an interactive experience. AR may entail a digital enhancement of the physical world (e.g., a graphic overlay on top of a real object) or a digital environment within which physical objects (e.g., the body) are integrated.

and events, manipulate input characteristics, and receive sensory feedback on their performance. Our design includes scaffolds for parents, resources that are made available to them and through which they can assist the child. Our analysis of the parent–child interaction that takes place draws on prior research employing similar methods to infer potential learning benefits in sites of informal learning—the analysis of how parents respond to children's intuitive interest and perceptual observations. Parents often provide unseen information on principles or causal mechanisms, an effective form of talk that is commonly called conceptual talk (Allen, 2002). Adopting this method permits the comparison of *MEteor* to other interactive science experiences and contributes to the growing literature on social learning processes that support informal science education.

Exhibits as Mediators of Conversations on Science

Simulations and other interactive technologies are beginning to shift focus onto the performative and socially expressive components of learning (Säljö, 2010). With these technologies, designers can produce exhibits that enhance content with engagement and interactivity by, for example, overlaying information onto artifacts or supporting the visitor's exploration with digitally enhanced objects that are responsive and provide guidance. The promise of these technologies is that they can bolster engagement and learning while simultaneously promoting and reinforcing social interaction among visitors (Elinich, 2011).

However, the relationship between interactivity of an exhibit and social interaction is complex (vom Lehn, Heath, & Hindmarsh, 2001). Early research has shown that families participate in more question-asking and answering when a child is engaged in simple forms of device interactivity than when they are simply reading labels (Blud, 1990). More recent research has found, however, that interaction with a device may not ensure social interaction characterized by engagement with underlying ideas (e.g., Narayanan & Hegarty, 2000). Heath, vom Lehn, and Osborne (2005) argue that highly interactive exhibits may actually inhibit social interaction, and field research has often documented this trend. Hsi (2003) showed how visitors engaged in a hands-on exhibit prefer to remain concentrated on a task and may even resist active participation by others (see also Lyons, 2009). Bystanders or family members may observe a child interacting with an exhibit, but they frequently do not consult knowledge resources (such as descriptions on labels) or convey their content to the children. Playful, visually rich, and technologically novel exhibits are attractive to children, and they may engage with the exhibit with parents becoming passive observers of their play. Fleck et al. (2002) found that when an exhibit is particularly fun to engage with, labels of how to use the exhibit or what it represents are not read, with parents only occasionally making affective comments.

Some other work has, however, been more successful with designing interactive technology for conversations. Key to promoting and guiding learning conversations appears to be providing some form of scaffolding. The "Be the Path" exhibit (Yoon et al., 2011), for example, merges physical interaction (joining hands) with digital technology (a visualization of electric conductivity). Children prompted to a discussion prior to producing the phenomenon by knowledge-building scaffolds (e.g., "Our hypothesis is . . . ") showed improved conceptual understanding compared to children who also produced the phenomenon though physical interaction but were not prompted by the scaffolds. Benjamin, Haden, and Wilkerson (2010) showed how simple previsit conversational guidelines and suggestions alter significantly caregiver–child discourse that enhances children's memories of a science center visit. Effects were also found on forms of talk: Both caregivers' and children's talk contained more *wh*-questions than in a control group (to which no guidelines were given). Other forms of scaffolding, such as games that families played before attending to science center exhibits, have also been successful in eliciting inquiry-like conversations while in the museum (Gutwill & Allen, 2010).

Taken together, these studies show how highly interactive exhibits have the potential for eliciting productive social interaction, but that they also have the ability to isolate the visitor (typically the child) from her social surroundings. Interactive exhibits are still viewed as promising environments for eliciting conversations because of their ability to show complex phenomena in action, but their design must be conducted in such a way that they elicit predictions ("what do you think will happen if you change this number?") and explanations of the observed event.

The expectations are that visitors, and especially family units, not only talk but exhibit specific forms of talk, in particular discourse that goes beyond what is immediately observable, such as discussion of underlying ideas and causal mechanisms within an interactive simulation. These expectations draw on research examining which kinds of talk are valuable to support children's engagement with ideas of science and in scientific reasoning.

Parent–Child Conversations in Informal Learning Environments

Several studies have examined family conversations related to scientific thinking as learning outcomes in informal science education settings (Allen, 2002; Borun, Massey, & Lutter, 1993; Crowley et al., 2001a; Gutwill & Allen, 2010; Tare, French, Frazier, Diamond, & Evans, 2011). Ash (2003) suggests that conversations are the primary means of instigating children's learning in science centers and museums. Stimulated by sensory experiences, conversations often mobilize conceptual knowledge that goes beyond those experiences and promote the connection to knowledge acquired in prior contexts (Zimmerman et al., 2010). Conversations are seen as scaffolds for learning that provide structure to a family's inquiry where children's understandings are explored and discussed (Ash, 2003). Through these conversations, children's thinking and language become gradually aligned with their more expert conversational partners, helping children to gain understandings that they would not have gained on their own or with their peers (Fender & Crowley, 2008).

Conceptual talk. In these studies, researchers rely on specific indicators in conversations to find evidence for science learning. Allen (2002) proposes the general category of *conceptual talk,* distinguishing it from other forms of activities such as perceptual talk (e.g., emphasizing a feature, commenting on an observation). Conceptual talk encompasses simple and complex inferences that go beyond what is observed and often provides an explanation or abstract description of an observation. Although a broad category, conceptual talk is commonly taken as an indicator for higher level engagement with science where children voice their understandings and parents engage with these understandings. At interactive hands-on exhibits, children may enact their understanding through physical manipulation, with parents supporting them with explanations or other forms of conceptual talk. Analysis schemes therefore often characterize a family conversation in relation to the conceptual talk contained within (e.g., Szechter & Carey, 2009; Tare et al., 2011; Kisiel, Rowe, Vartabedian, & Kopczak, 2012)

Explanations. Within the general category of conceptual talk, explanations are recognized as critical contributions to children's learning of scientific thinking and science content knowledge (Benjamin et al., 2010; Crowley et al., 2001a; Kisiel et al., 2012; Randol, 2005). Crowley et al. (2001a) argue that explanations "present excellent opportunities for children to articulate and revise their theories of scientific phenomena, with guidance from parents and other adults" (p. 714). Fender and Crowley (2008) provide experimental evidence from a science center study showing how parents' explanations increased children's understanding of underlying causal mechanisms of an interactive artifact. Research in developmental psychology has provided support for the relationship between children hearing an explanation and learning gains. For example, children are better able to transfer problem-solving strategies across similar problems if the demonstration of the strategy is accompanied by an explanation (Crowley & Siegler, 1999). Though the specific role of explanations remains a subject of study, there is significant evidence that explanatory exchanges are strongly related to the development of children's cognitive competencies (Wellman, 2011).

Though much of prior work has focused on parent's explanations, conversations in informal learning environments also present opportunities for children to develop their own. Children very rarely provide explanations spontaneously (cf. Haden, 2010), and when they do they typically respond to parental explanations or prompts. Parents or caregivers may elicit explanations with explicit request for them, or through more subtle forms of requests (e.g., other *wh*-questions and challenge statements) that invite explanations and justifications (Gaskins, 2008; Humphrey, Gutwill, & the Exploratorium APE Team, 2005). Benjamin et al. (2010) suggest that one benefit of children providing explanations is that parents or caregivers can discover children's ideas and/or lack of knowledge.

Strategic support. In addition to providing explanations, parents may give metacognitive support to children as well as prompting them to plan, think ahead, and reflect. Research in developmental psychology has shown that children's approach to problem solving and inquiry is less systematic than adults' (e.g., Dunbar & Klahr, 1989; Schauble, 1996). Children tend to persist on manipulating a smaller number of variables and to search for evidence that is consistent with their beliefs. Parental support to improve scientific thinking has been observed in informal conversations, where parents often give guidance on strategies. Such support has been observed also in science centers. For example, Kisiel et al. (2012) show how parents and children jointly engage in scientific inquiry, with parents promoting children's process of making claims and providing support for evidence collection. Crowley et al. (2001a) document multiple cases where a parent helps a child to collect 'evidence' at an interactive exhibit. In this role, parents are less seen as providing content knowledge, but rather as guiding children in their own construction of that knowledge (e.g., Callanan, Shrager, & Moore, 1996).

Age and gender effects on parent–child talk. Several studies have examined possible correlations between conceptual talk, age, and gender. Jipson and Callanan (2003) and Tenenbaum and Leaper (2003) found no differences in the number of explanations given by parents to children aged 3–10, although parents perceptions of their child's interest and knowledge have a bearing on parents' question-asking and explaining (Crowley, Callanan, Tenenbaum, & Allen, 2001b; Palmquist & Crowley, 2007). However, gender correlations were occasionally identified. Tenenbaum and Leaper (2003) find that parents are more likely to believe that science is less difficult and more interesting for sons than for daughters. In museums, parents will explain more often to boys than to girls (Crowley et al., 2001b). Szechter and Carey (2009) argue that differences in talk related to gender may correlate with parents' attitude toward science and ideas about gender roles. In most of these studies, families were observing "static" exhibits, and differences in talk may correlate with the child's expected behavior. By giving each child an equally active role in interacting with an exhibit, as in *MEteor*, it is possible gender effects may show a different pattern.

Science Learning With Embodied Technologies

Prior research has shown that the degree of compatibility between physical action and concepts strongly affects the learning of concepts (Martin & Schwartz, 2005). Segal (2011) provided evidence that learning from physical engagement is dependent on the degree of alignment between physical movement and the concepts being learned. Immersive and interactive learning environments draw on numerous theoretical perspectives including constructivist and situated learning theories, and in recent years there has been particular emphasis on the embodied and perceptual affordances of virtual learning environments that involve physical enactment and tangible manipulation (Black, Segal, Vitale, & Fadjo, 2011; Lindgren & Johnson-Glenberg, 2013). Starting with Piaget's work on children's causal reasoning (Piaget, 1956), there has been a rich literature on the experiential and sensorimotor foundations of science knowledge and learning (e.g., Brown & Hammer, 2013; diSessa, 1993), with many researchers advocating for these embodied and physical experiences to be incorporated into science instruction (e.g., Clement, 1993). The potential to use immersive simulations and virtual reality environments to generate learning has been cited by numerous researchers and designers in a variety of contexts (e.g., Bailenson et al., 2008; Dede, Salzman, & Loftin, 1996; Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2014; Lindgren & Johnson-Glenberg, 2013). Body movement and physical activity has recently been leveraged as a means of conceptual development in science both without technology (Plummer, 2009; Richards, 2012) and using emerging digital media platforms to teach about basic kinematics, circular motion, etc. (Enyedy, Danish, Delacruz, & Kumar, 2012; Johnson-Glenberg et al., 2014). The idea behind all of these interventions is that children learn by enacting their ideas and predictions about science with their bodies (e.g., running along with the asteroid they have launched with an initial velocity and predicting its trajectory when it approaches a planet) and the simulation giving feedback about how close their ideas are to normative ideas.

The Present Study

To examine parent–child conversations in the context of an immersive and interactive augmented reality simulation, the *MEteor* environment was installed at a science center in the southeastern United States. *MEteor* had been studied previously in a laboratory setting and had demonstrated its effectiveness in promoting changes in understandings of basic ideas of physics in space, as well as other effects, such as improving attitudes toward science and boosting learners' feelings of self-efficacy (Lindgren et al., 2016). These effects, however, were found for individual learners in relatively controlled sessions using *MEteor*. In this study, we set out to investigate the social learning effects of *MEteor* in an authentic informal science education environment.

MEteor is composed primarily of a 30 foot × 10 foot interactive floor space (Figure 1). The simulation features a launcher (a virtual spring mechanism) through which the child propels an asteroid into a field of outer space that is populated by objects such as planets with gravitational attraction. The environment prompts the child to predict and stay with the asteroid as it traverses its course through the simulation space. This often includes curving, speeding up, and even orbiting a virtual planet. Through interface cues and the motivation to succeed in a game-like performance environment, the design intent was for the child to actually "feel" the effects of gravity on physical objects in space by engaging these phenomena via their sensorimotor perceptions.

The child's overall task in *MEteor* was to hit a target located in the virtual space. Once launched, the asteroid was likely to be diverted by gravitational forces that, together with

Figure 1. The *MEteor* interactive floorspace. Participants launch their asteroid using the spring (middle right) in an attempt to hit the square target (bottom center). Behind the child is a table with multiple screens that parents and other visitors can gather around.

the initial launch parameters (position, angle, velocity) determine its trajectory. The child received real-time feedback while running or walking with the asteroid through a circle marking her current position in the simulation field. The color of the circle changes from green to red if the distance between her and the moving asteroid increases. The ability to track the child's exact position and display the trajectory of the asteroid in real time was accomplished using laser-scanning technology and multiple coordinated projectors mounted on the ceiling.

The participating child was asked to carry out a set of four interrelated tasks that required an understanding of an object's movement in space, the effects of gravity, the properties of orbits, etc. Task 1 is designed to convey ideas of frictionless motion without the effect of gravity. In Task 2, a large planet exerting substantial gravitational force is projected at one side of the simulation field with the target (a red square) in close proximity. To complete this task, the child had to launch the asteroid on a trajectory that takes into account both the bending and acceleration effects of gravity. In Task 3, the child was asked to hit a target located behind a smaller planet. This required understanding that gravity can cause objects to arc dramatically around planets, and that the strength of gravity is related to the planet's mass. Finally, in Task 4, the child had to launch the asteroid such that it achieved a stable orbital path around a virtual planet. From this task, the idea was that children obtain a sense of the "constantly falling but missing" phenomenon that keeps celestial objects in orbits, as well as the elliptical shape and changing speed of orbiting objects.

The simulation leverages the affordances of mixed reality environments to enact ideas and receive multisensory and physical feedback on these ideas (Lindgren & Johnson-Glenberg, 2013). For example, children are typically aware that gravity can pull an object and change the direction of its movement, but within *MEteor* we see that they are often unaware of the acceleration effects of gravity. This means that children initially lag behind the just-launched asteroid, and then they must accelerate their own bodies to catch up. The design encourages prediction and prompts the gradual understanding of the mechanism behind the simulation and the physics of force and motion in space.

Figure 2. The three screens visible to the parents. Screen 1 (left) displays the prompts to parents such as "Why aren't they reaching their goal?" and "How can they adjust their movements?" Screen 2 (middle) presents a birds-eye view of a just-completed launch: the position of the launcher and the planet, and the trajectories of the asteroid and the child's walk or run. Screen 3 (right) presents graphically the normative view of planetary motion (including orbits) using the appropriate terminology. This screen was designed to encourage parents to use science terms, as well as making links between the simulation and science models.

In contrast to most other interactive exhibits, the physical activity elicited by *MEteor* is aligned with the science phenomenon being simulated (the movement of objects in space). Many interactive exhibits invite physical interaction that does not map directly onto the concepts students are working to understand. A simple push button to produce clouds, for example, has little physical similarities to process by which clouds are formed. In *Meteor*, this alignment between the child's physical activity and the target learning concepts is designed to be very close. The human body becomes embedded within the digital environment that takes the body's movement as input. Children must regulate with their body the position, angle, and speed of the virtual asteroid, while considering the forces at play in the simulation. The close relationship between physical activity and thinking in *MEteor* allows children develop their understanding of the simulation concepts through enactive play. Having parents and other visitors in the environment allows children to reflect upon and verbalize this understanding, and gives parents the opportunity to prompt for explanation and shape the child's process of reasoning.

The extent and form of parental guidance is explored in this study. As we argued in the literature review, the combination of rich sensory experiences, high exhibit interactivity, and social interaction has produced mixed results. Inspired by prior exhibit and task designs that showed promising results (Benjamin et al., 2010; Gutwill & Allen, 2010; Yoon et al., 2011) our design includes resources to scaffold parents and to distribute knowledge in such a way that productive conversations are elicited.

Specifically, parents who are positioned at one side of the simulation view three screens that displayed (1) a task description, (2) a schematic replay of the most recently completed launch, and (3) supplementary information and questions about gravity and celestial motion (Figure 2). By giving parents selective access to additional knowledge and information, we hoped to support parents' understanding of the simulation, prompt them to support the child by conveying that understanding, as well as elicit requests for support by the children themselves.

RESEARCH QUESTIONS

We aim to investigate whether whole-body interactive performance simulations can support parent–child conversations characterized by conceptual talk, the joint and iterative construction of an understanding, and strategic support.

Research Question 1: Do parents provide a "conceptual layer" for children's rich sensory and physical experiences within these immersive technologies? In other words, do parents react to children's intuitive focus on the mechanics of the simulation, their physical experiences, and immediate perceptual observations with conceptual talk?

Research Question 2: Do parents support the child in developing iteratively a more complete understanding of a scientific phenomenon, an understanding that adapts with varying input parameters? Is there evidence that parents and children are integrating previous actions and outcomes with current activities to improve future performance?

Research Question 3: Do parents give strategic and metacognitive support to the child immersed in a highly interactive, performance-oriented simulation? For example, do parents help guide the exploration of variables and help children draw inferences from observations?

METHOD

Participants

Participants were 101 families with a child between the age of 9 and 13 (mean age: 10.8, $SD = 1.3$) visiting a science center in the Southeastern United States. The frequency for each age was the following: 9 years old: 8.9%, 10 years old: 37.8%, 11 years old: 24.4%, 12 years old: 21.1%, and 13 years old: 7%. A science center volunteer was positioned about 20 feet away from the simulation looking for families that showed interest in the simulation and who appeared to have a child in the middle school age range. The simulation was visible from many positions within the exhibit hall, and there was frequently visitors gathered around observing *MEteor*. Families were approached and asked whether they wanted to "try out the simulation and participate in a study". Some families were composed of more than one child, and occasionally also joined by grandparents or parents' friends, or also friends of the child. We analyzed only sessions where at least one parent was present. We excluded sessions with too many active participants where visitors were talking over each other. Only four sessions were excluded based on this criteria, yielding the sample of 97 valid sessions (38 girls, 59 boys). Thirty-two families were composed of one parent and one or more children. In 57 sessions, both parents were present. In eight families also grandparents or parent's friends were present. When both parents were present, it was common that only one parent communicated with the child, whereas the other parent looked at the supplemental information screens or occasionally gave brief affective comments on the performance. We chose to focus our analysis on parent–child dyads (one parent only) because these were the target participants in many studies on free-choice learning as well as in educational psychology research, and thus it allows us to make comparisons with findings of other research. The gender ratio of the parent primarily communicating with the child was 44 females to 53 males.

Procedure

Prior to the session, the consent process was administered. At this point, the parents were informed about the resources that were made available to them so that they could potentially support the child's performance and reasoning. In the meantime, the child was given a brief tutorial on the basic functionality of the *MEteor* simulation.

One person only communicated with the parents and the child and then gave technical support during the session (e.g., a new task had to be started manually). In about half of the session, this person was a researcher, whereas in the other half young science volunteers covered this role. The researchers and volunteers followed this script while talking to the parents:

> In this game, a target needs to be hit with an asteroid. The asteroid is launched with a spring mechanism that can be adjusted for position, angle, and force of launch. In front of you are information screens. They give you information about the physics of planetary motion and the task; you can see a replay of a launch on one of the screens as well.

During the session, the operator did not communicate with the parents or the child unless technical assistance was needed. If parents asked questions about the simulation or the task, they were directed to the information screens.

Data Collection. Data were collected for 1 week during the full span of visitor hours at the science center. We collected two kinds of data: observational data (written annotations) and video- and audio-recordings of interactions. An observer sitting at one side of the simulation, orthogonal to the side where the parents were located, annotated the group size and participants, and their time of arrival and departure. A nonintrusive video camera and voice recorder were used to capture talk, gestures, and parent's attention to the screens. The video camera was placed at the angle opposite to the launcher and the parents' and information screen's position (Figure 1 is a screenshot from the video recording). This allowed us to capture most of the simulation field and as well as a front-view of the parents. Audio was captured by the camera microphone, and a portable voice recorder placed close to information screens.

Owing to having two sources of audio (the in-built camera microphone and a portable voice recorder), audio quality for parents' talk was of sufficient quality that transcription was possible. However, about 30% of children's talk was not recorded at a sufficient quality to transcribe. It appeared to us that sometimes children were speaking only to accompany their own reasoning, which may have been why it was difficult to hear.

Materials. We relied on transcriptions of parents' and children's talk, as well as the video images. The verbalizations of participants were segmented into utterances, with added annotations of other actions (e.g., gestures) when needed.

Our primary operationalization of the unit of "utterance" is that it is a complete communicative unit expressing an idea (Carter & McCarthy, 2006). This means that an utterance could sometimes comprise more than one proposition or brief expressions. For example, short instructions that are in sequence (e.g., "Move over here, and now move to the left. Good, now you can launch") are counted as a single utterance. Furthermore, all expressions of affect or encouragement that occurred immediately after a trial were counted as a single utterance. It was common that, for example, a parent would comment on the results ("oh, you almost got it this time"), and then praise the child ("well done!").

Coding followed a standard iterative process of identifying and categorizing utterances. The development of the coding scheme (see Table 1) relied on prior work, such as Randol (2005), Fender and Crowley (2008), and Tare et al. (2011) on the basis of which the primary distinctions between categories of talk were drawn. Because our interest was in capturing the degree to which parents would engage children in interactions with conceptual content, the important distinctions are between instructions, explanations, and parent's invitation to explain, reflect, and make predictions.

The first author coded all videos and transcribed utterances. To obtain a measure of the reliability of that coding, a doctoral student coded 25% of utterances that were randomly selected. Interrater agreement (Cohen's kappa) was .93. By most accounts (e.g., Bakeman, Quera, McArthur, & Robinson, 1997), a kappa value above .81 is considered "excellent agreement."

TABLE 1
Classification of Parent Utterances Across All Sessions

Category	Total	Percentage of Total Utterances	Percentage of Sessions Where Utterance Type Was Present
1. Instructions	471	36.7	87.6
2. Strategic support	110	8.6	38.1
3. Explanations			
Local	63	4.9	30.9
Science concepts	92	7.2	34.0
4. Model construction	69	5.4	30.1
5. Invitations to explain	56	4.4	28.9
6. Task	106	8.3	54.6
7. Affective participation	270	21.0	79.3
Not interpretable	47	5.0	

Coding. Classification of an utterance proceeded by checking whether it could be classified according to one of the following categories: instructions, strategic support, explanations, invitations to explain, model construction, task, and affective comments.

Instructions are utterances where a parent explicitly tells the child what to do. Instructions were focused on the setting of the spring launcher or they were targeting a specific outcome. Instructions aimed at setting the launcher could refer to the child ("come over here") or to the launcher itself ("give it more force"). Instructions targeting the outcome did not refer to the launcher or the child, but rather to what the child should try to achieve in specific terms ("try to bend it around!"). Often these instructions were accompanied by gestures such as when a parent traced the desired trajectory with a hand, or when she pointed to a spot in the simulation field to which the child should aim their launch.

Strategic Support. Utterances that support the child's problem solving are classified as strategic support. Support could be provided at the stage of preparing for the launch, by directing the child's attention to events after the launch, and, more generally, by focusing her attention on what parents deemed to be the important features of the simulation mechanism. This category aimed to capture parental assistance on science reasoning, i.e., suggesting to the child that they try to explore the input options systematically, to attend to observations that the child may have missed, and to see those events as data from which to make inferences. Children have a tendency to attend to perceptually salient events or to remain focused on a single input variable for explanations (Dunbar & Klahr, 1989; Schauble, 1996). We observed that children had a strong tendency to set the launcher by changing all three variables simultaneously when permitted, and parents may provided help by saying "now, you keep the position the same, and change the angle"). Parents may provided that support directly or ask children to think and plan before a launch ("wait, wait, what are you trying to do?").

Explanations. We define as "explanation" an utterance conveying knowledge about the mechanisms of the simulation. Ideally such descriptions included causal connectives, but more often consisted of short statements inferred from the asteroid's behavior. For example, "the asteroid got attracted by the planet" conveyed a causal relationship between the force of gravity and the asteroid's trajectory; exclamations such as "there is gravity!" uttered following the observation of the asteroid bending also implicitly conveyed a sense of causality. Additionally, propositions that are formally predictions (e.g., "if you shot it there, the gravity won't be able to grab it") may described a mechanism, and if they do, they are coded as 'explanations' as well. More ambiguous, but still coded as an explanation was feedback on the child's actions, such as when parents' explained that the child used "too much force." Such feedback or comments were only coded as explanations if they were voiced immediately after an event (e.g., crashing or missing the target) and were directed at a specific object or event. Comments about the asteroid's behavior such as "it went too fast" were not coded as explanations because, we argue, they would require one or two steps of referential inference (e.g., the launcher, the physics forces, or the child's action).

We distinguished between local explanations and explanations that connect to science knowledge. Local explanations refered to the mechanisms of the simulation such as when a parent explained that "you need more power because it is pulling the asteroid in." An example of an explanation connecting to science knowledge was "it has got to get stuck in gravity to get around."

Invitations are defined as all utterances where parents elicited a child's reflection, or asked her to explain. Parents may have asked the child to "step back" and reflect on an event ("so, what happened here?"); or parents may have asked to think about the simulation before launching ("how will the gravity of the planet pull your asteroid?"), including by drawing on science knowledge ("how does the size of the planet affect the bending?"). As for coding requests for explanations, we distinguished between explicit requests ("why did the asteroid go off?") and more subtle forms such as challenge statements ("are you sure this is what is going on?," "but what about the speed?").

Model Construction. This category was developed to identify utterances that build on prior utterances where a parent and a child iteratively constructed a better understanding of the simulation across launches and tasks. Talk about comparisons between launches and/or tasks were the salient signs that the dyad engaged in thinking back about observations and launcher settings, to draw inferences that could improve a current launch (e.g., "how is this different from before?"). In contrast to all other coding categories, to classify an utterance in this category we took into account previous and subsequent utterances. Classification in this category occurred *after* the primary classification. Specifically, we checked whether an explanation or invitation to explain was part of a sequence of utterances where the current situation was compared to a previous situation, i.e., we checked whether comparisons between launches and tasks were made explicitly. If this was the case, the original coding was replaced with a coding for model construction. For example, if an utterance was coded as an "explanation," and then it was found that it was part of a sequence of utterances where a parent engaged the child in a longer conversation about the mechanism of the simulation, the utterances was coded as "model construction." We therefore distinguish between "explanations" and "invitations" that occur in isolation, and those that occur in a longer sequence.

Task. The task was displayed on a screen (e.g., "Put your asteroid in orbit around the planet") to which only parents had access, and they were to convey that task to the child. We counted in this category only instances where the task was conveyed for the first time or when parents reminded the child of it without adding an explanation or instruction.

Affective Participation. Affective participation included encouragements ("well done!") or any other emotional expression ("oooh!"). We included such expression in the analysis so as to give a comprehensive picture of parent's participation.

RESULTS

The results are presented as follows: Taking into account all sessions, the degree of parental participation is examined and the forms of talk are analyzed. Through a correlation analysis, we identify two kinds of sessions, where either instructions or conceptual engagements are predominant. These quantitative analyses will provide data to partially answer the research questions, which are discussed after the presentation of the quantitative results. For each question, we discuss representative excerpts.

Participation

A typical participant required a few minutes of introduction and experimentation with the *MEteor* environment before they were sufficiently accustomed to the interface functionality. For this reason, we did not start our analysis of talk until Task 2, which is the first task in which a participant had to accommodate some external force to be successful at hitting the target in the simulation space.[2] The design of *MEteor* is based on the notion that participants will develop an understanding of the underlying mechanisms—and ultimately critical ideas of normative physics—by iteratively refining their launches on each trial. Most participants started this iterative process at the beginning of Task 2, and this is also where parents typically started assisting the child.

On average, the analyzed session period lasted for 7:56 minutes ($SD = 2{:}18$) and children completed an average of 16.2 launches ($SD = 4.2$). We transcribed and analyzed a total of 1,457 utterances (1,284 parents', 173 children's), with an average of 15.2 ($SD = 9.7$) utterances per session. The large spread is indicative that in a few sessions there was very little or no talk, whereas in other sessions there were lengthy exchanges. The number of utterances ranged from 0 to 45. Since the amount of talk correlates positively with the number of launches, we calculated the average number of contributions by launch. The result was an average of 0.96 utterances per launch ($SD = 0.6$). We identified 12 sessions (12%) with no or little talk, using a threshold of not more than 0.3 utterances per launch.

Based on this initial analysis, we further examined specifically whether parents would assist the child or participate in another form. In this latter category, we counted affective contributions, comments or feedback without informational content, and encouragements. Such contributions were frequent, but they normally co-occurred with other contributions. For example, parents may have instructed the child or helped her reason about the relevant science, and as a result they were more engaged in the play, leading them to comment after a launch or encourage the child to try again. In only six sessions (6%) was there verbal participation but no evidence of assistance. In 79 sessions (81%), parents provided some form of assistance to the child. Taken together, verbal participation by parents of some form occurred in 85 sessions (87%).

Table 1 presents the breakdown of all parental utterances into the seven categories. Affective participation was a common form of interaction (21% of all utterances), and happened typically at the end of a launch. Parents normally voiced encouragement (e.g., "Well done!") or gave short unspecific comments on the outcome of the trail (e.g., "ooh, almost!"). Less frequent (8%) were task descriptions (e.g., "you have to hit the red square").

[2]The utterance analysis was conducted on a unit that we will refer to as a "session." A session starts at Task 2 and ends when the child exits the simulation after the last launch of Task 4. The child is familiarized with the basic mechanisms of the simulation in Task 1 where no planets—and hence no gravitational forces—are present. The child in Task 1 is simply launching the asteroid directly at the planet, and so there usually was very little talk at this stage. Typically during Task 1 parents are familiarizing themselves with the supplemental information screens.

TABLE 2
Correlation Coefficients and Their Significance Levels of Talk Categories, Gender, and Age

	Instructions	Strategic	Invitations	Explanations	Model Construction	Task
Gender	.076	−.139	−.088	−.93	−.94	−.003
Age	−.104	.155	.141	.052	.147	.092
Instructions		−.230*	−.423**	−.416**	−.371**	.148
Strategic			.773**	.532**	.484**	.03
Invitations				.441**	.482**	−.068
Explanations					.565**	.108
Model Construction						.017

Note: **Correlation is significant at the 0.01 level (two tailed). *Correlation is significant at the 0.05 level (two tailed).

They were often read from the screen at the beginning of a task and may be repeated when a launch was not successfully completed. The most important result concerns the forms of assistance (the first five categories), which we will describe in the next section.

Types of Talk by Session

Based on the quantities of each category of talk, we examined the occurrence of at least one instance of each category by session (right-most column in Table 1). We find that instructions occur in 87.6% of sessions, strategic support in 38.1%, invitations in 28.9%, explanations (local and/or scientific) in 38.14%, model construction in 30.1%, and conceptual talk in 29.9%.

To be able to account for the difference between instructions and deeper engagement through dialogues, we group explanations, invitations, strategic support, and model construction together (cf. Tare et al., 2011). Thirty percent of utterances are part of dialogues, whereas 36.7% are instruction. We counted 471 instructions (mean: 6, SD = 4.1), 155 explanations (mean: 1.9, SD = 1.2) and 56 invitations (mean: .6, SD = .5); 110 times parents supported children with problem-solving strategies (mean: 2.2, SD = 1.8), and 69 (mean: .5, SD = .6) utterances were part of longer sequences of utterances where a parent and a child engaged in constructing an understanding of the simulation.

A question emerging from the data in Table 1 concerns the distribution of types of talk across families. This question is relevant in general—do parents only either instruct or engage the child in a dialogue? The high standard deviations of all categories are indicative that different kinds of talk were well distributed over the families. That is, an individual family may engage in different kinds of talk: they would instruct, explain, elicit explanation, and so on. A correlation analysis shows (see Table 2), however, that all types of conceptual talk (categories 2–5) correlate positively with each other, and that *all* types of conceptual talk correlate negatively with instructions. We interpret these two analyses as meaning that families preponderantly instruct *or* engage the child in a dialogue, but that neither instructions nor dialogues are exclusively present in an individual family's talk. We confirm this interpretation by grouping families into "primarily instructional" (less than 30% of conceptual or strategic talk), "primarily dialogical" (less than 30% of instructional talk), and balanced. The numbers of families for each grouping are "instructional", 35 (44.1%); dialogical, 23 (29.6%); and balanced, 21 (26.3%). These findings must be interpreted by comparing them to characteristic parent–child conversation at interactive exhibits, which we will turn to in the Discussion section.

A further question emerging from Table 1 concerns the distribution of conceptual talk across families; for example, do parents only explain or only support the child's planning, or does an individual family engage in more types of conceptual talk? The question emerges from the similarity in percentages of the presence of Codes 2 to 5 in families: the percentages average to 32.4, with a small standard deviation ($SD = 3.4$). To answer the question, families were grouped into mutually exclusive categories: whether only 1, or 2, or 3 codes of Codes 2 to 5 were present. We find that in 25 families only one code was present, two codes in 15 families, three codes in four families, and all four codes in 11 families. This analysis indicates that multiple codes in the same case (family) do occur with moderate frequency and conclude that the similarity in percentages for cases where at least one of the codes 2–5 is present (see Table 1) does not mean that these are the same families.

The findings show that *MEteor* can engender interactions where parents engage children in reasoning and support understanding of the simulation that goes beyond what is immediately experienced. They also show that in some sessions an understanding of the mechanisms of the simulation—which may be helpful for the child to understand the physics of planetary motion—is constructed gradually and iteratively by posing and answering questions. We will discuss excerpts of such sessions in the next section.

Age and Gender

We did not find statistical significance in any of the correlations between the child's gender or age with the type of talk (Table 2). We further conducted analyses to examine whether, for example, fathers engaged differently with daughters than they did with sons. A generalized linear mixed model to conduct an analysis of the three-way interaction (gender (parent) $\times$ gender (child) $\times$ type of talk) did not, however, show any statistically significant effects.

Children's Talk

We counted a total of 175 utterances by children, an expectedly much lower number than the one for parents' talk. Children talked when asked by a parent to provide an explanation, when asked to respond to questions such as "what are you trying to do?" or occasionally commented on their own performance with short affective expressions ("I got so close this time!"). Most importantly, however, children often asked for assistance (28%). These requests typically followed an unsuccessful launch ("what has happened to the asteroid?") or preceded the first launch in a new task ("what do I need to do?").

To categorize children's talk, we developed a second coding scheme: Category 1 was used to code children's talk about what they planned to do next, Category 2 to code children's explanations, Category 3 to code children's request for assistance, and Category 4 to code children's affective expressions. Table 3 presents the categories and frequencies of all children's utterances for all sessions. Transcribing children's utterances was particularly difficult because of children's changing positions and distances to the audio-recording devices. Thirty-one percent of their contributions could not be transcribed sufficiently to be analyzed because of poor audio quality.

Children primarily asked for assistance (28%) or they explained when prompted to do so by their parents (23%). About half of such explanations relied on science knowledge, whereas half were local causal explanations. Occasionally, children would comment on their own performance with affective expressions (6%).

TABLE 3
Classification of Children's Utterances Across All Sessions

Coding Category	Example	Percentage
Talk about planned activity	"I'll try to shoot it over there"	12
Explanations	"because it got attracted"	23
Asking questions	"what is going on here?" "what should I do now?"	28
Affective expressions	"this was sooo close!"	6
Not interpretable		31

We turn now to provide answers to the research questions based on the quantitative results, and illustrate interactions with excerpts.

Research Question 1

Do parents provide a "conceptual layer" for children's rich sensory and physical experiences within these immersive technologies? In other words, do parents react to children's intuitive focus on the mechanics of the simulation, their physical experiences, and immediate perceptual observations with conceptual talk?

One hundred fifty-five instances of parent's talk were coded as explanation (12.1% of all talk). In several cases, explanations are offered in a single contribution, in response to an event.

> **Parent**: Have you seen how this time the asteroid went around the planet and did not crash into it? This is because you gave it more speed, so the gravity was able to catch it less. [*science explanation*]

Explanations and conceptual talk more commonly occurred, however, when engaging the child in a dialogue. The following excerpts show several examples of explanations and examples of how parents react to children's perceptual talk or local explanation with conceptual talk. The excerpt is part of an exchange of a mother and a boy, aged 8, in Task 2. As was commonly observed for the first launch in this task, the children are unaware of the possibility of gravitational attraction of the planet (this is the first task where the planet is in the simulation field). The asteroid, normally launched directly at the target, is deflected and exits the simulation. Gravitational acceleration is visible at the end of the trajectory.

> ((asteroid is launched, misses target))
> **Parent**: Oh, do you see what happened? Where did your asteroid go? [*inviting observation*]
> **Child**: It went really fast! [*perceptual observation*]
> **Parent**: Really fast? Did you see where it went? Did you follow it? Where did it go? [*inviting observation*]
> **Child**: Over there. ((pointing to side of field))
> **Parent**: Yes, it went around the planet. Do you know why that is? [*inviting explanation*]
> **Child**: It made a curve. [*perceptual observation*]
> **Parent**: Yes, the planet pulled the stone in. [*local explanation*]
> **Child**: So I have to shoot over there. ((pointing to the side of the target opposite the planet)) [*planning*]
> **Parent**: Yes, you have to compensate. How are you going to do this? [*re-describing plan*]
> ((Child changes angle of launcher pointing to the place indicated before))

This parent's talk overlays the child's perceptual talk with terms that include prompts toward an explanation ("pulling," "compensating"). She directs the child's attention to the effect of the planet and conceptualizes the child's more immediate ideas ("I have to shoot it over there": "yes, you have to compensate"; "[it went] over there": "yes, it went around the planet"). It is notable how the boy reacts to the mother's "around" with "curve"; and then, as this term signals to the mother that the child has a more appropriate description of the trajectory, she asks the child for an explanation of the curving.

The last two utterances show how, when parents convey their ideas, children often react by planning the next launch, i.e., setting the launcher and predicting the trajectory. That is, parental understanding is translated into physical manipulation and the prediction of a trajectory that is then enacted physically.

We present another excerpt on how children's immediate perceptual observations intersect with parents' conceptual talk. This excerpt, also at the first launch of Task 2 where gravitational attraction is evident for the first time, is between a father and a boy (aged 10), The boy's focus on what is immediately observable can be seen in his responses to questions. He provides primarily observations ("It's gone"), rather than explanations, and, when more explicitly prompted for explanations, his answer refers to the manipulation of the launcher ("because I angled it").

> ((child launches asteroid which is deflected and misses the target))
> **Parent**: Do you see what happened? [*inviting observation*]
> **Child**: It's gone. [*perceptual talk*]
> **Parent**: It went to Jupiter, right? Why did it go to Jupiter? [*eliciting explanation*]
> **Child**: Because I angled it. [local explanation]
> **Parent**: It's got a gravitational pull. So it's going to pull the asteroid towards Jupiter. [*science explanation*] So what are you going to do? [*inviting planning*]
> **Child**: . . . farther away? [*planning*]
> **Parent**: Yes, you need to get farther away from Jupiter. [*instruction*]

In dialogues of this kind, incorrect ideas about notions such as gravity or orbits may emerge, and parents may correct them. We observed only a few instances of correcting misconceptions and therefore did not use a separate category for them. We'd like to report, however, an excerpt where the child (a girl aged 10) appears to think that gravity is a circular "flow" in one direction, a misconception that appears to be common in children (Kavanagh & Sneider, 2006). The launch preceding this exchange resulted in the asteroid crashing into the planet. The child appeared to think that the asteroid was caught in the "flow of gravity." To avoid that flow, she proposes to launch the next asteroid to the opposite side of the planet ("the gravity won't be able to pull it"). Based on this exchange, we may infer that the child thinks that gravity flows around the planet in a semicircle. The parent reacts to this idea by pointing out that gravity "is everywhere," addressing the child's incorrect idea on the location of gravity, but not the idea that there is a "flow." This explanation is not followed by further talk, but by two more launches. In these launches, the child does not target "the other side"—the side where, according to her, there is no gravity. It appears that the parent's explanation had the effect of the child backing away from her idea, though, as no further talk occurs, we cannot know whether the child has revised her ideas.

> **Parent**: So, basically, how can you change it so that the gravity takes it less? [*inviting planning*]
> **Child**: Go around it [tracing a trajectory to the left side of the planet] or go back. [*planning*]

Parent: Going around the other side? I think you are going to hit the planet again. [*inviting planning*]
Child: But the gravity is going this way [tracing with an outstretched finger a curved path to the right of the planet]. [*science explanation*]
Parent: What's in your head? [*inviting reflection*]
Child: If I shoot it there (pointing to left side of planet), the gravity won't be able to pull it. [*science explanation*]
Parent: It will pull it anyway. It is everywhere. [*science explanation*]

Research Question 2

Do parents support the child in developing iteratively a more complete understanding of the scientific phenomenon—which varies in dependence of input parameters? Is there evidence that parents and children are integrating previous actions and outcomes with current activities to improve future performance?

Thirty percent of families engaged in longer exchanges where observations and experiences of prior launches, and tasks were compared to more fully understand the simulation phenomenon. We coded utterances in this category when there was explicit talk about comparisons, and included also explanations and invitations if they were preceded by a comparison.

Consider the following conversation between a mother and a boy, aged 11. In this excerpt, the parent helps the child to think through an observation (a bending of the asteroid the child did not expect). The conversation occurred in Task 3 after the child had just completed the first launch of that task. The launch was unsuccessful because the child underestimated the acceleration of the asteroid, which missed the target and left the simulation field. He launched the asteroid close to the planet to induce bending of the trajectory, but was not aware that the closer the asteroid is to the planet, the more it will accelerate, and therefore the effect of gravity on bending will be weaker.

The observation about "stronger gravity" is an observation about the effect, i.e., of the asteroid being exposed longer to more gravitational attraction because it is closer to the planet than in Task 2. The mother's response is important: she signals neither approval nor disapproval ("hmm") but questions his explanation ("Why would it be greater? Is it bigger?"). Her strategy appears to be to engage him in thinking what data would be needed to support his explanations and to direct him toward an alternative explanation.

Parent: Is it anything different between what you see now [in Task 3] and what was there before [in Task 2]? Are they exactly the same? [*comparison*]
Child: Ah, wait, the gravity is stronger. [*explanation*]
Parent: Is that what you see? [*directing attention*]
((child launches asteroid. The launch results in a crash))
Parent: Hey. What do you see is different? [*comparison*]
Child: The planet has changed position. [*observing*]
Parent: Yes. Position shift. Anything else? [*comparison*]
Child: It is stronger. [*observing*]
Parent: Can you figure out why that would be? [*invitation to explain*]
Child: Hmmm, the mass? [*explanation*]
Parent: Hmm. Why would it be greater? Is this a bigger planet than the other one? [*invitation to explain*]
((child launches asteroid. The asteroid bends around the planet, but misses the target))
Parent: Oh, you got it around. Why is that? [*invitation to explain*]
Child: It went faster. [*explanation*]

The final contribution shows how the mothers' engagement, which is primarily strategic, leads the boy to notice that when approaching the planet, the asteroid accelerates significantly. The excerpt just discussed is notable in the way in which the mother does not correct the boy, but engages him in reasoning so that he can understand whether his explanation ("it is stronger") is supported by the data or not.

The following excerpt is part of an exchange between a father and a boy (age 8) in Task 2. The father invites the boy to compare the objects in the current simulation field to the previous ones and adapt his strategy to the new task. The boy's observations are frequently corrected by the father. Prior to this exchange, the boy had launched the asteroid directly toward the target as was usually done during Task 1 (where no gravitational force is present in the simulation field). The projected straight path was deflected by the gravity of the planet, and the asteroid left the simulation field between the target and the planet. His explanation — that a "black hole" has attracted the asteroid—means that he has some awareness that black holes attract objects. His next explanation that "planets have orbits" may mean that he attributed the observed bending to "orbits" that children often misconceive as predefined fixed paths (cf. Kavanagh & Sneider, 2006).

The exchange is typical in that errors frequently give rise to conversations, with parents directing children's attention and inviting them to provide explanations. Once the child appears to have a good understanding, the focus returns to the launcher mechanism ("So, what do you do to get around?").

((child launches asteroid for the first launch of Task 2; asteroid is deflected by planet and misses target))
Parent: So, what is different from before? Do you see this? [*comparison*]
((child launches asteroid again, misses again))
Parent: Do you see the red square? Why did the asteroid not go there, and go off like that? What is on the floor? [*directing attention*]
Child: A black hole [*explanation*]
Parent: It's a planet. And what do planets have? [*invitation to explain*]
Child: Orbits [*explanation*]
((child launches asteroid, crashes))
Parent: Listen to me. There is a planet that wasn't there before, and you want your asteroid to go to the red square [pointing to square]. So what do you do? [*planning*]
Child: I go around [*planning*]
Parent: Yes. So what do you do to get around? [*planning*]
((child moves the launcher to the right, into a more optimal position))

Research Question 3

Do parents give strategic and metacognitive support to the child immersed in a highly interactive, performance-oriented simulation? For example, do parents help guide the exploration of variables and help children draw inferences from observations?

We turn now to excerpts that illustrate how parents support children with strategies, i.e., by asking them to think about the forces in the simulation field and plan the setting of the launcher. We found 110 instances of strategic support (8.6% of total talk).We included in this category talk that directs children's attention to observations and tells them to use these observations as evidence, and talk that guides children in the more systematic exploration of the launcher settings.

The following excerpt is part of longer exchange that happened between a father and a boy (aged 10) in Task 3. In this task, the target is located behind the planet, and the parent prompts the child to reflect on observations and to plan ahead before the next launch. The exchange is initiated because, apparently, the boy launches the asteroid with little reflection on how to improve on the previous launch. The boy also appears to be focusing entirely on the outcome of the launch ("[I need to] avoid the planet and get through to the target") rather than effectively selecting the launch parameters. The father draws the boy's attention to the variables that determine a launch, and finally tells him to set the launcher settings sequentially.

> ((boy launches the asteroid; it misses the target))
> **Parent**: Mike, what are the 2 things that determine you hitting the red square? The 2 things? [*inviting reflection*]
> **Child**: Avoiding the planet and getting through the target. [*planned activity*]
> ((child launches asteroid; it crashes into the planet))
> **Parent**: Mike, I'd like you to wait. How do you determine the speed of the asteroid? [*inviting planning*]
> **Child**: The more you pull it back ((the launcher)), the more speed it has [*local explanation*]
> **Parent**: Correct. And how do you determine where the asteroid goes? [*inviting planning*]
> **Child**: With the launcher. [*not categorized*]
> **Parent**: Yes, but how? What do you change? What are the 2 things? [*inviting reflection*]
> **Child**: Where I put it. [*local explanations*]
> **Parent**: Ok, but not only. Also the angle. These are the 2 things: the position and the angle. [*local explanation*]
> **Child**: Ok. [*not categorized*]
> **Parent**: So, you set them one by one. You set one, and keep it, then you set the other. [*planning*]

In the following excerpt, between a mother and a boy (aged 9) in Task 4, the mother provides strategic support and also invites the child to think about how he successfully completed the previous task. Task 4 is the final and most difficult task. It requires the understanding that a small force is sufficient to get the asteroid moving, because once the asteroid is in movement, gravity will accelerate it. That acceleration should then push the asteroid past the planet. Once the distance to the planet increases however, gravitational attraction will decelerate the asteroid and it will turn again toward the planet therefore starting to orbit.

Because the task requires to curve the asteroid around the planet, the mother reminds the boy about his success in the previous task. In that task, he often missed the target because he launched the asteroid with too much force. One launch, where the asteroid was sent with less force, was successful because by traveling at a lower speed, gravity had a bigger effect on the asteroid, and it bent around the planet. The mother reminds him of the effect of gravity on the trajectory and the speed of the asteroid. She tells him that he already succeeded in "getting the asteroid around," in "wrapping it around." She directs his attention to the "variable" (force of launch) of the launcher setting with which the initial speed is set. At the first launch, the asteroid crashes into the planet. The mother subsequently walks the child through the launch. She tells him to change only the speed setting and keep the other settings (variables) constant.

> **Parent**: So Joshua, slow down before you do the next step. You got it to go around the planet and actually hit the red square previously, when you changed, what? [*comparison*]
> **Child**: The speed. [*explanation*]
> **Parent**: The speed. So you got to make it wrap around this planet twice. What are you going to do . . . what variable can you adjust? [*inviting planning*]
> ((Child launches the asteroid; it crashes into planet.))

Parent: The asteroid is with you now, so don't leave the green square until you have decided what you're gonna do. [*inviting planning*]
Parent: You know that going around this thing is probably going to have something to do with speed. Right, Josh? How do you get speed in this situation? [*inviting planning*]
Child: Go backwards. [*planning*]
Parent: Anything else that helped you get speed? [*comparison*]
Child: Slingshot around the planet. [*planning*]
Parent: What do you mean? Can you explain that? [*inviting explanation*]
Child: Slingshot around the planet and use the gravitation to hold it.[*planning*]
Parent: Is it going to bounce off something to go around or will the gravity do it for you? [*inviting prediction*]
Child: It will come back. [*prediction*]

DISCUSSION

Augmented and mixed reality technology offers new ways to structure children's activities and to design resources so that parents will support the child. Gutwill and Allen (2010) argue that current interactive exhibits often do not provide enough manipulation options to promote prolonged and personalized engagement and keep children and parents interested in exploring and talking about a phenomenon. Our exhibit provided multiple opportunities for children to experience a science phenomenon that they themselves had produced. Parents hence supported children's learning of scientific practices such as relying on observations to formulate explanations and of the systematic study of the relationship between actions and results. Parents accomplished this by bringing structure to children's efforts and specifically by eliciting explanations and prompting them to reflect and plan ahead.

The results of our analysis compare favorably to Randol's (2005) who examined family conversations of 149 visitor groups at eight interactive exhibits to detect patterns of science reasoning. He found that visitors overall, and also small families (one or two adults with one or more children) rarely went beyond what the exhibit afforded (turn a dial, lift a lever, roll a wheel, etc.), and also rarely drew conclusions from observations or made generalizations. The exhibits Randol (2005) examined were limited in manipulation options and interactivity, which may account for these findings. Crowley et al. (2001a) studied parent–child dialogues at an interactive zoetrope, an exhibit that allows more manipulation options. Though some frequencies, such as the amount of strategic support, are comparable in the studies, Crowley et al. (2001a) found that in very few sessions parents provided explanations linked to science knowledge (6%) compared to our finding of 34%. Age group differences (4–8 in Crowley, 2001a, vs. 9–14 in our study) may account for this finding, although prior studies did not identify correlations between age group and number of parents' explanations (Jipson & Callanan, 2003; Tenenbaum & Leaper, 2003). It is more likely that parents provided explanations because of the resources made available to them. By displaying relevant science knowledge, the *MEteor* screens acted as prompts for parents to contribute to the child's experience with that knowledge. Parents may have used the content of the screens for information, or the screens may have influenced how they decided to contribute.

A related difference is that parents in the Crowley et al. (2001a) study often provided short just-in-time explanations ("explanatoids") without engaging the child into longer dialogues on the phenomenon or the relevant science. Such brief explanations also occurred in our study, but we find additionally that in 29.9% of sessions parents engaged children in longer dialogues aimed at constructing a deeper understanding of the simulation. The construction of that understanding is most likely prompted by the effort to explain the varying observations at different launches and tasks. This lends support to the value of exhibits that implement an iterative progression with multiple trials and task.

Overall participation is higher in our study compared to Crowley et al. (2001a). They report that in 57% of sessions a parent provided basic guidance, compared to our sessions where 87% of parents participated. We also note that a substantial percentage of talk around *MEteor* are affective comments (21%). This form of participation is often lower at other exhibits, or not reported in research papers. Thus, a comparison of the proportions of forms of talk rather than frequencies would most likely yield even higher differences in these comparisons.

Children appeared to be more active in providing explanations in our study compared to those described in other studies. Szechter and Carey (2009) find that children very rarely provide explanations but contribute to a conversation mostly with perceptual talk. As children's explanations are often not counted, but instead overall conceptual talk is reported, we may infer from the low frequency of conceptual talk (cf. Gutwill & Allen, 2010, p. 711) that children's explanations are generally low. Tare et al. (2011) include children's explanations in their analysis of conversations at a noninteractive exhibit on evolution. The study found a low frequency (7.71%) as well as few instances of children asking questions (11.8%). Overall, parents in our study engaged more in what Tare et al. (2011) call 'explanatory talk', i.e., talk that supports children's exploration either strategically or with content knowledge. Standardizing our frequencies in relation to Tare et al. (2011) frequencies of affective talk, task directions, and uncategorized talk, 'explanatory' talk constitutes 42.9% of all talk in our study, compared to 34.3% in Tare et al. (2011).

The relatively high number of instructions overall and sessions that are primarily instructional are a concern that requires an examination of causal and contributing factors. Demographic and other data (socioeconomic status, level of parental education, science attitudes, attitudes toward technology) may be helpful to identify these factors in future studies. Prior research has shown that level of schooling correlates with causal and other explanations in museums. Parents that had completed high school typically engage in more explanatory talk than those that had not (Tenenbaum & Callanan, 2008). However, a potentially confounding variable are parenting styles that may correlate with education. Gaskins (2008) finds that the parents' understanding of how children learn and their own role in facilitation affects the way they talk to children in museums.

However, there may be intrinsic explanations for why didactic engagement is relatively high. We posit that the spring launcher is an object that is easily established as the shared object of reference. Instructions always refer to the launcher ("it needs to have more angle") or the child manipulating the launcher ("move over here"). Unlike parents, children cannot see the screen showing a just-completed launch, and thus an object that could potentially function as the focus of a discussion is not available. Parents may have difficulties to convey their understanding, and hence may prefer to give instructions. Future research will explore whether adding abstract representations of events to which both the child and the parent have visual access increases the frequency of dialogues. Such representations have been employed in online learning environments. Suthers and Hundhausen (2003), for example, found that shared abstract representation can successfully guide conversations toward more abstract ideas.

An open question remains whether the desire of the child and the parents to succeed affects the way they talk. *MEteor* was placed in a public space, and often other visitors were observing. The question about whether this situation led to more didactic versus dialogic interaction turns partially on the question of what talk parents, and maybe also children, deem to be more effective to be successful. Very few studies have explored how parents talk to children in these contexts. However, Gleason and Schauble (2000) found that when parents and children collaborate on a task, but are required to succeed and have limited time available, children are relegated practical tasks (such as moving parts of a device). Their study analyzed parental talk and compared postsession knowledge convergence, from which they concluded that parents do not convey their own emerging understanding to the child. In our study, in contrast, parents very frequently conveyed their understanding to the child, and sometimes went to great lengths to articulate an effective explanation.

CONCLUSIONS

The 2009 NRC report proposes a model of science learning that emphasizes the significance of engaging children in scientific reasoning and reflection on science activities and of the development of interest in science (NRC, 2009). The report advocates for the increased use of informal learning environments due to their ability to combine interest and spontaneous engagement with scientific content. Structuring children's activities and guiding their understanding toward a normative view of science, whereas maintaining an informal character, remains one of the most challenging tasks for science educators and designers. The synergistic effect combining children's conceptual engagement with their physical and sensory experiences is recognized as a central form of science learning in informal situations (Falk & Dierking, 2008; Wishart & Triggs, 2010). While the role of parents in providing conceptual support has been studied in several situations of informal learning, little work has yet examined whether and how parents provide that support at science center exhibits that are immersive, playful, and performance driven. Studies on interactive technologies in informal learning spaces have shown that individuals often remain focused on a task and may be unreceptive to other's comments or interest (Heath & vom Lehn, 2009; Hsi, 2003), missing the important social interaction that is recognized as being valuable for learning. Our study has shown that by creating interactive performance spaces that invite reflection and iteration, and explicitly including conversational scaffolds, parents are brought into the child's activity and children often make successful attempts to get assistance from their parents. This design leverages the capabilities of emerging digital technology to combine multiple layers of experiences, engagement, and information where the essential pathways for knowledge exchange are enhanced.

Funding for the *MEteor* project was provided by the National Science Foundation (DRL-1114621). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding institutions. We would also like to thank the entire MEteor team, especially J. Michael Moshell, Eileen Smith, Charles Hughes, and Emily Johnson; and the Science Center staff, who gave us access to the Center, as well as the volunteers.

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