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Young Children's Knowledge About the Moon: A Complex Dynamic System

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Abstract The purpose of this research was to use a multidimensional theoretical framework to examine young children's knowledge about the Moon. The research was conducted in the interpretive paradigm and the design was a multiple case study of ten children between the ages of three and eight from the USA and Australia. A detailed, semi-structured interview was conducted with each child. In addition, each child's parents were interviewed to determine possible social and cultural influences on the child's knowledge. We sought evidence about how the social and cultural experiences of the children might have influenced the development of their ideas. From a cognitive perspective we were interested in whether the children's ideas were constructed in a theory like form or whether the knowledge was the result of gradual accumulation of fragments of isolated cultural information. Findings reflected the strong and complex relationship between individual children, their social and cultural milieu, and the way they construct ideas about the Moon and astronomy. Findings are presented around four themes including ontology, creatures and artefacts, animism, and permanence. The findings support a complex dynamic system view of students' knowledge that integrates the framework theory perspective and the knowledge in fragments perspective. An initial model of a complex dynamic system of young children's knowledge about the Moon is presented.

Keywords Astronomy · Conceptual understanding · Early childhood · Moon · Sociocultural

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Piaget was instrumental in developing research programs that focused on individual, psychological constructivism (Vosniadou 2003). He showed how children of similar ages give similar responses to questions and that it is possible to see a progressive evolution in the kinds of explanations that children give for phenomenon such as the origins of the Sun and Moon. Piaget also described how children, "do not attain the correct answer or the natural explanation in one bound but seem rather to grope for it and during these gropings may be seen numerous traces of beliefs of the preceding stages" (Piaget 1929, p. 351). Thus, he highlighted the importance of prior knowledge to the process of teaching and learning. While Piaget did not ignore the social and cultural aspects of learning, greater attention to the work of Vygotsky and other researchers (Moll 1990) has resulted in a shift of focus towards aspects other than the cognitive when researching the processes of learning (Tsai and Wen 2005; Venville 2004). Vosniadou (2003), for example, pointed out that, at present, most researchers agree that conceptual change is not something that takes place solely in individual minds, "but a process that can be facilitated (or hindered) by sociocultural factors and educational settings" (p. 380).

Not only has the way we view learning shifted since the time of Piaget's initial, extensive interviews with children in the 1920's, but science itself has shifted in a number of directions (Ravetz 2005). Most importantly with regard to the science that is the focus of this research, our understanding of astronomy and space has increased exponentially. Recently we celebrated the 40th anniversary of the first human landing on the Moon. We have sophisticated combined telescopes such as the Very Large Telescope Interferometer (VLTI) at the European Southern Observatory in Chile that enables astronomers the kind of precision that can differentiate the two headlights of a car at the distance of the Moon (see: http://www.eso.org/public/astronomy/teles-instr/paranal.html). As a consequence of these developments in science, images of the Earth and the Moon from space are commonplace in the mass media including television, the internet, books, magazines, and newspapers, to which children of all ages have considerable exposure. People can travel around the Earth in a matter of hours and have instantaneous audio and visual conversations with people in different parts of the world.

The research presented in this paper is situated in this complex and intriguing intersection between changes in the way we view learning and changes in the way that science and astronomy have become available to young children. The purpose of the research was to conduct a qualitative investigation of young children's (ages three to eight) conceptions of the Moon. Moreover, the purpose of the research was to investigate the broader social and cultural environments in which the children live and learn and the impact those environments have on their understandings of the Moon. More specifically, the research questions were:

1. What conceptions do young children (ages three to eight) have of the Moon?
2. How do social and/or cultural factors affect or influence children's conceptions of the Moon?

The broader purpose of the research was to go beyond these questions to use the findings to contribute to recent debate from a theoretical perspective about the way that young children develop knowledge and the structure of that knowledge. In the following section we provide a literature review on research about children's understandings of the Moon. Subsequently we develop a theoretical framework that will enable discussion about how our research contributes to the current debate about the structure of knowledge.

Literature Review and Theoretical Framework

Children's Conceptions of the Moon

Since Piaget's initial work there have been numerous studies conducted with elementary children and their understanding of the Moon. An examination of this literature reveals that it is mostly focused on children's understandings of Moon phases (e. g. Baxter 1989; Schoon 1992; Trundle et al. 2007). Haupt (1950) researched first grade children's understanding of what caused the Moon to have different shapes. He found 61.9% of the children stated they did not know, 19% claimed cloud coverage, one child reported "the night hides some of the parts", and another said "the north wind is greedy and eats the Moon a bite a day and the south wind blows it back" (p. 233). Since then, several studies described young children using a 'blocking' notion, such as clouds covering the Moon, to explain why the Moon's appearance changes (e. g. Baxter 1989, 1995).

Baxter (1989) described five notions used by children aged between nine and 16 years to account for Moon phases. These notions included: a) clouds covering the Moon; b) planets casting a shadow on the Moon; c) the Sun's shadow falls on the Moon; d) the Earth's shadow falls on the Moon; and, e) the correct explanation of the phases due to the portion of the illuminated side of the Moon visible from Earth (p. 509). Of these many explanations accounting for the Moon phases, the predominantly held notion by the children in the Baxter study was that the Earth's shadow falls on the Moon. Schoon (1992) conducted a cross age study with 1,213 students. The survey revealed 48.1% of the subjects surveyed to believe that the different phases of the Moon are caused by the shadow of the Earth falling on the Moon, and, an even more interesting finding, was that this conception became more popular with age where 69.5% of college level students accepted this notion. More recently, Hobson et al. (2010) showed that computer simulations may enable young children (ages seven to nine) to understand the lunar phases by reducing the burden on their cognitive capacity. A related study conducted by Trundle et al. (2008) analysed Moon phase representations as illustrated in children's literature. Often these illustrations were inaccurate and the authors linked such occurrences to possible alternative conceptions held by children.

In this current study, we went beyond this focus on Moon phases to investigate how young children think about the Moon in more comprehensive ways; that is, its basic nature and appearance, its origination, whether children think the Moon is a living thing, and where they think the Moon is when it is not visible in the sky. Our reason for taking this approach was to probe more deeply the way that children's knowledge about the Moon is structured so that we could make a theoretical contribution to the literature about the structure of knowledge in more general terms. In order to do this we provide in the following paragraphs a theoretical framework that outlines a current status of limbo that we perceive in the literature.

The Structure of Knowledge

The structure of knowledge is probably one of the most contested and least agreed upon issues in education today. "It is puzzling and ironic, given its centrality, that no consensus exists on this issue" (diSessa 2008, p. 35). The controversy revolves around a question of whether naïve ideas are structured into coherent theoretical structures, referred to as 'framework theories' (Vosniadou et al. 2008) or whether naïve knowledge is fragmented and piecemeal displaying only limited features of a system that could be described as a theory (diSessa 2008).

Several researchers have argued that knowledge is structured in the mind in the form of theories or cognitive, explanatory structures that "help us find the deeper reality underlying surface chaos" (Carey 1985, p. 194). Theories are thought to organise knowledge in people's minds and are used as a coherent framework for understanding the world around them. Vosniadou (1999) argued that knowledge acquisition starts early in infancy and is guided by general principles organised into "framework theories" (p. 2). Research suggests that children start with only a few of these theories, for example, a naïve theory of mechanics (Vosniadou 1994), and a naïve theory of psychology (Carey 1985).

From a *knowledge in pieces* perspective, diSessa (2008) claimed that descriptions in the literature of naïve theories are rarely elaborate and often are stated in a "single phrase or sentence" (p. 37). Further, explanations of the relationships between the aspects of framework theories are often "missing or minimal" (p. 38) indicating, diSessa claimed, that it is inappropriate to refer to framework theories as coherent. diSessa argued that intuitive knowledge is not structured in a coherent manner, rather, it is a collection of simple elements known as phenomenological primatives (p-prims) that originate from the child's superficial interpretation of the world around them (diSessa 1993). P-prims are subsequently organised into a conceptual system, and learning involves collecting and organizing pieces of knowledge into these larger structures.

Recently, *coherence* and *fragmented* perspectives have been somewhat reconciled with Vosniadou et al. (2008) explaining that "our position is not inconsistent with the view that something like diSessa's p-prims constitute an element of the knowledge system of novices and experts" (p. 23).

> Our proposal that the conceptual system consists of different kinds of knowledge elements (such as beliefs, presuppositions and mental models) is also consistent with diSessa's proposal that we need to focus not on single conceptions but on rich knowledge systems composed of many constituent elements. (Vosniadou et al. 2008, p. 23)

diSessa (2008) explained that the difference in perspectives can be considered to be one of degree, where "no one can believe that people are 100% coherent and consistent, and no one can believe people have nothing more than a completely incoherent jumble of ad hoc ideas" (p. 39).

Brown and Hammer (2008) provided a synthesis of the literature and concluded that "there is strong evidence at both ends of this phenomenological spectrum" (p. 135) that support both Vosniadou and diSessa's positions. Importantly, Brown and Hammer suggest that a model of intuitive knowledge "must account for the full range of established phenomena" (p. 135). In order to do this, Brown and Hammer proposed a "complex systems perspective on students' conceptions" (p. 135). From this integrated perspective, Brown (2010) argued that both Vosniadou and diSessa view students' conceptions as arising from a complex system of knowledge elements.

Brown (2010) explained that if we look carefully, there is significant overlap in diSessa's and Vosniadou's perspectives and that this overlap leads to a multidimensional complex dynamic system view of students' conceptions and conceptual change. Brown is careful to point out there are still important points on which diSessa and Vosniadou do not agree. Brown claims, however, that both agree that a unitary misconceptions perspective, that is, the consideration of single misconceptions without consideration of the underpinning knowledge structure is simplistic and misleading.

Brown further argues that diSessa's p-prims are not fragile or random, and states that while diSessa would balk at calling p-prims theory-like structures, p-prims are far from unrelated knowledge fragments and "possesses a kind of dynamic structure that in certain

contexts would be surprisingly robust." (p. 3). In this sense, Brown argues that both Vosniadou and diSessa see students' conceptions as arising from a complex system of knowledge elements. Brown uses the analogy of a concept map with many nodes and interconnections to represent such a complex system of knowledge elements. Brown elaborates that by using this model, both diSessa and Vosniadou's perspectives suggest a dynamic and evolving structure. Finally, Brown points out that both Vosnaidou and diSessa views support the idea that students' conceptions arise from a system of knowledge elements in which some knowledge elements are implicit or intuitive and others are more consciously employed.

The Structure of Astronomical Knowledge

It is important for the purpose of this current research to situate the theoretical perspectives discussed in the previous section in the scientific field of astronomy. The issue of how astronomy is structured in the minds of young children has been extensively researched with regard to children's conceptions of the Earth but much less so with regard to children's conceptions of the Moon. Vosniadou and colleagues have given considerable attention to astronomical mental models. Vosniadou (1994) used the term *mental model* to refer to a particular kind of mental representation of external reality. She explained "it is an analog to the state of affairs that it represents" (p. 414). Vosniadou (1994) assumed that mental models are dynamic, and that they are created on the spot for answering questions and/or solving problems. She explained that mental models are generated from and are constrained by the underlying conceptual structures, that is, the framework theories, and a given mental model provides only partial information about conceptual knowledge.

Vosniadou (2003) argued that young children's mental models of the Earth suggest that they embed this concept in a physical framework theory and not an astronomical framework theory as we would expect of adults. The physical theory is constrained by "entrenched presuppositions" (Vosniadou 1994, p. 413) that objects are continuous, solid, have no action at a distance, are acted upon by gravity and have inertia. Vosniadou's research suggests that children think of the Earth as a physical body that is solid and stable and is supported by ground or water. According to Vosniadou, children also think that space is organised in directions of up and down and that unsupported objects 'fall down'. Vosniadou claimed that the entrenched presuppositions are universal across cultures, but they can be mediated by children's culture. For example, children in all cultures will believe that 'all things fall down' and, therefore, the Earth must be supported by something; but children's views about how the Earth is supported will vary depending on their cultural experiences. For example, due to local folklore, some Indian children believe that the Earth is supported on a giant turtle's back (Samarapungavan et al. 1996). Vosniadou and Brewer (1990) also found that due to local geographical differences, the American children they interviewed tended to explain that the Sun goes down underneath the Earth, but the Greek children in their study tended to say the Sun goes down behind the mountains or sea. As children mature and develop the concept of the Earth undergoes a major reorganization that involves the reconceptualization of the Earth as an astronomical body.

An alternative view to that of Vosniadou's thesis about children's mental models of the Earth being embedded in an intuitive theory of physics is presented by Nobes et al. (2003) who adopt a similar perspective to diSessa (2008) of knowledge in pieces. These researchers critique Vosniadou and colleagues' approach saying that their use of two dimensional drawings during data collection might have led to misrepresentation of

children's understandings. Nobes et al. present an alternative theory that children are "theory neutral" (p. 73) and the development of understanding of the Earth involves the gradual accumulation of fragments of social and cultural information that may be inconsistent with one another. The researchers cite the research of Siegal et al. (2004) in Australia and Schoultz et al. (2001) in Sweden that showed that children frequently demonstrate aspects of scientific understanding of non-intuitive, cultural information such as the Earth is 'round' or a 'sphere' and little evidence for initial or synthetic mental models as described by Vosniadou. Nobes' et al. (2003) data indicated that the children's knowledge of the Earth was fragmented and there was no indication that their responses were guided by intuitions of flatness or support as would be expected if mental models were constrained by a theory of physics. Their findings were consistent with diSessa's (2008) perspective because they indicated that knowledge is gradually accumulated, piece by piece of loose fragments of social and cultural information that remain disorganised until the coherent scientific notion of the Earth is gained (Nobes et al. 2003).

Importance of this Research

This research is important and adds to the literature in four ways. First, as explained above, the research conducted on children's understandings of the Moon converge on the phases of the Moon and tend to be conducted predominantly with children over the age of nine years. This current research adds to this literature because we worked with young children, between the ages of three and eight, to explore their broader, more holistic conceptions of the Moon. Second, the research is important because we examined the structure of children's astronomical knowledge beyond what is already known with regard to the Earth by using a different astronomical phenomenon, the Moon. Vosniadou (1994) said that, "more research on the development of the concepts of the 'sun,' 'moon,' 'stars,' and 'planets' is needed in order to answer" (p. 413) the question about whether these astronomical bodies are considered in the same way as the concept of Earth and whether the domain of astronomy is consistently conceived to belong to the domain of physics by young children. Third, this research is important because we have taken a multidimensional approach to data collection by examining both the conceptual and sociocultural aspects of the children's knowledge of the Moon. We actively investigated the social and cultural environments of the participants' lives that may have influenced their conceptual understanding.

Finally, and most importantly, this research is the first empirical study that we are aware of that has explored the utility of Brown and Hammer's (2008) complex dynamic system view of children's knowledge. Initially we were interested to investigate whether young children embed their conceptions of the Moon in a physical framework theory as suggested by Vosniadou (2008); or, whether knowledge about the Moon is developed in a fragmented manner, as suggested by Nobes et al. (2003), diSessa (2008), and Siegal et al. (2004). The integrated theoretical perspective of Brown, however, provided us with an avenue to move on from the limbo between these two perspectives, to recognise the powerful similarities between them, and develop more compelling understandings of the way that knowledge about the Moon is structured in the minds of young children.

Methods

The research presented in this paper was conducted in the interpretive paradigm and utlized a multiple case study design (Stake 2006; Yin 2003) involving in-depth interviews with ten

children and their parents in various locations in the United States of America (US) and Australia. Case studies provide unique examples of real people in real situations, in unique contexts where events can be seen as dynamic and unfolding (Merriam 2009). Children were purposefully selected to participate as case studies by the researchers in order to involve children who we felt would feel free to honestly share their ideas and opinions with us (Stake 1995). The contexts of the US and Australia were selected as we felt that the children's location in the different hemispheres added important diversity, but at the same time, all children lived in a modern, western culture. Background information about the children can be found in Table 1. We interviewed seven girls and three boys between three and eight years of age. The children lived in a number of states in the US including Texas, Ohio, and Minnesota as well as two Australian children who both lived in the state of Western Australia. There are two sibling relationships amongst the children, Kayla and Rick were sister and brother as were Winnie and Eric (Table 1).

Interview Protocol

We utilized a qualitative approach to data collection because it is best situated to identify children's concepts and cognitive structures. The interview protocol for all interviewees and their parents was developed by Louisell et al. (2009) from Piaget's questions about the origins of the Moon in *The Child's Conception of the World* (Piaget 1929). The interview probed the children's general understanding and perceptions of the Moon, their beliefs about the movement of the Moon, whether they feel the Moon is living, and where the Moon is when it is not visible in the sky. The questions were listed with less direct questions (such as, "Can you tell me anything about it [the Moon]?") first in the hope that the child would volunteer ideas. If the child's ideas about a particular issue we were interested in were not forthcoming, the interviewer would eventually ask more direct questions, e. g. "Can the Moon follow you?" (See Appendix 1 for the full interview protocol.) The interview protocol was semi-structured with the interviewer following up responses from the child and pursuing avenues of thought relevant to the research questions. The interview protocol served to define a standard approach that all three interviewers used during the interview process. In addition, the second author, Louisell, conducted two initial interviews and posted the DVD to the other two researchers so that consistency between interviewers was further enhanced.

In order to address issues about interviewing about astronomy raised in the literature (see Blown and Bryce 2006), the protocol included a section that adapted Applebee's (1978) research on children's construction of stories by requesting the child to tell a story about the Moon. At the conclusion of the child's story, each child was asked if the story they just told really happened in order to see if the child was telling a story they understood as fact or fiction. Through analysis of the children's Moon stories, further light could be shed upon their understanding of the Moon and their original lunar interpretations. While analysing the brief stories, special attention was paid to what the story's center was, what role the Moon (or moons) possessed in the story, and what language was used to describe the Moon. Giving children the opportunity to freely weave a story about the Moon, allowed them to introduce new characters, make connections between the characters, and illustrate creativity with unique lines of reasoning.

The parent interview protocol (see Appendix 2) was designed to ascertain any insights they might have about their child's experiences that may have influenced his or her ideas about the Moon. The questions were quite general; however, interviewers were able to discuss specific ideas raised by each child with their parent.

Table 1 Background information about participants

Pseudonym	Sally	Steve	Lizbeth	Robyn	Ellen	Susan	Kayla	Rick	Eric	Winnie
Sex	Female	Male	Female	Female	Female	Female	Female	Male	Male	Female
Age at interview	6	5	6	8	6	6	3	5	7	6
Home location	Western Australia	Western Australia	Ohio	Ohio	Texas	Minnesota	Minnesota	Minnesota	Minnesota	Minnesota
Schooling	First Grade	Kindergarten	Kindergarten	Second Grade	Kindergarten	First Grade	None	None	First Grade	First Grade
Household	Mother, Father, one sister (9 years)	Mother, Father, three sisters (15, 13, 9 years)	Mother, Father, one sister (3 years)	Mother, Father	Mother, Father, two sisters (9, 15)	Mother, Father, no siblings	Mother, Father, one brother (6 years)	Mother, Father, one sister (2.5 years)	Mother, Father, one brother and one sister	Mother, Father, one brother and one sister
Father's occupation	Butcher business owner	Sports retail	Radiologist	Financial officer	Lawn turf consultant/ manager	Professor	Electrician	Electrician	Optometrist	Optometrist
Mother's occupation	Homemaker, part time work in butcher shop	Homemaker	Medical sales	Retired job coach	Mathematics teacher	Homemaker, part time academic	Teacher	Teacher	Human resource specialist	Human resource specialist

Interview Procedure

All children were interviewed in their own homes with the exception of one child, Lizbeth, whose interview took place in her Aunt's home. The home context was deliberately selected for the interviews because we felt it would make the children and their parents feel comfortable to articulate and explore their understandings of the Moon. We felt the home context would enable participants and their parents to reflect on any sociocultural factors that may have influenced the children's understandings of the Moon and thus would enable us to collect data that would answer Research Question 2. The interview started with a little conversation about a small talk topic such as sport or the weather to help the child relax with the interviewer. Interviews with the children were followed by an interview with the child's parent or parents, depending on who was home at the time. The child usually stayed in the room during the parent interview, but sometimes they went into another room or outside to play if they wished. Data were collected by videotape and audiotape. The entire interview process including arrival, setting up equipment and small talk generally took about an hour. The child interviews took between ten and 20 min and parent interviews between 15 and 30 min depending on the interviewees' level of engagement and the degree to which they were forthcoming with information.

Data Analysis

The audiotape recording for each interview was fully transcribed and the videotape was then viewed while the researcher read the transcription to check gestures and comments that could not be heard clearly on the audiotape recording. The transcripts were modified for accuracy and annotated with comments based on the video recording. Transcripts from interviews with the children and their parents were then scrutinised for social and/or cultural information about the children's conceptions. For example, social events, such as discussions with their mother or father about the Moon, or cultural information, that is, relevant factors related to the child's and/or the family's way of living such as going to a restaurant or learning at school were noted. The three researchers individually highlighted such aspects of the transcripts that were important with regard to the research questions and wrote case studies about each of the children they interviewed (Louisell et al. 2009; Venville 2009; Wilhelm 2009). The researchers subsequently met in person on two occasions, once in Europe and once in the US, to compare their findings and to isolate common themes of importance to the research questions. In this way, several themes that indicated connections between the captured social and/or cultural milieu of the child and their understanding of the Moon were isolated. This process was guided by Merriam's (2009) description of 'category construction.' Merriam qualifies that "I see a category the same as a theme, a pattern, a finding, or an answer to a research question" (p. 178) and that the challenge is to construct categories or themes that capture some recurring pattern that cuts across the data. Based on interviews with two children, five themes were initially developed including: 1. the Moon, rockets and astronauts; 2. the non-living Moon; 3. movement of the Moon; 4. the yellow Moon; and, 5. views from the Moon. Excerpts from all case studies then were examined by the researchers and distributed into the themes. As part of this process, the themes were refined and coalesced into the four new themes that are used to structure the findings in this paper including: 1. ontology; 2. creatures and artefacts; 3. animism; and, 4. permanence. Excerpts from interviews that were representative of the final themes were selected for inclusion in this paper. The themes were mostly mutually exclusive as suggested by Merriam (2009), however, some data were consistent with more than

one theme. For example, statements by children about the Moon moving away when it can't be seen were categorised into the movement of the Moon theme and the permanence theme.

Research Quality

We have used the strategy of triangulation at a number of levels in order to enhance the "credibility" of the findings (Merriam 2009, p. 213) or the correspondence between the research and the real world of the children who participated. Denzin (1978) proposed four types of triangulation, all of which we have used in a rigorous manner. First, we triangulated sources of data, that is, we collected data from ten children, their parents as well as artefacts such as books. Second, we used multiple methods to generate data in that we used direct questioning during the children's interviews and we used the story telling method previously explained. We also captured the data with video and audio recording. Third, we employed triangulation of investigators with three researchers involved in collecting and analyzing data as well as writing the case studies and generating themes (Louisell et al. 2009; Venville 2009; Wilhelm 2009). The researchers met and discussed the process and findings in person on two occasions and in an iterative process by email. Finally, we employed triangulation of theoretical perspectives, that is, we viewed the data through different theoretical perspectives, including the 'coherent theories' and 'knowledge in pieces' perspectives, as well as a 'dynamic system perspective' of knowledge as outlined in the theoretical framework.

Findings

Each of the themes that emerged during the data analysis is presented and discussed below. Codes in parentheses after children's pseudonyms refer to the child's home location (AUS-Australia, MN-Minnesota, OH-Ohio, and TX-Texas) and their age in years. For example, "Sally (AUS, 6)" indicates that at the time of the interview Sally lived in Australia and was six years of age.

Theme 1: Ontology

Bliss (1995) describes children's ontological judgments about the world as how children imagine the basic nature of objects and events. Under this theme we examine children's understanding of the basic nature of the Moon, in particular their musings early in the interview in response to questions such as, "Can you tell me anything about it [the Moon]?" Early in her interview, Sally (AUS, 6) said that the Moon has "holes" in it. She didn't know what causes the holes and it wasn't clear whether she was referring to craters or holes as can be found in Swiss cheese. Later when looking at photographs of the Moon, Sally said that some of the holes are purple and some are white, which indicated she was referring to craters. When asked, she said that she didn't know what the Moon was made out of. Similarly, Lizbeth (OH, 6), when asked early in her interview to describe the Moon, said there were holes in it:

> Lizbeth: It was a circle. It had these little holes in here.
> Interviewer: What were these holes? What were they for?
> Lizbeth: Maybe, maybe, maybe, maybe for little things to go in, maybe little pebbles fall on it.

When asked how she thinks the Moon was made? Kayla (MN, 3) said, "In the sky, of snow." This interview took place at the kitchen table, next to a sliding glass door that led to a deck outside. Everything in view was covered with snow. In the near distance, a frozen, snow-covered, lake could be seen. Kayla kept looking out at the snow as she talked; thus, the many references to snow.

Early in his interview, Steve (AUS, 5) mentioned that he thought the Moon, "Is very big and it's a circle." When asked what colour he thought the Moon is he said its "yellow" but couldn't give an explanation as to why it is yellow. Later in the interview, Steve said the Moon is made out of plastic, like his cricket bat, which also happened to be yellow.

Interviewer: Do you know what the Moon might be made out of?
Steve: Plastic.
Interviewer: Plastic, why do you think that?
Steve: Why?
Interviewer: Mm, what else is made out of plastic?
Steve: Bats… I've got … three [cricket bats]

After the interview, the interviewer saw Steve's plastic cricket bat and noticed it is yellow. It is possible that Steve's ideas that the Moon is yellow and plastic, were associated with his sporting cultural experiences. Later in the interview, when shown the telescopic photographs of the Moon, Steve readily changed his culturally constructed view that the Moon is made of plastic to a scientific view that the Moon is made of "rocks."

Sally (AUS, 6) indicated that if she was standing on the Moon, she could see stars. When Sally was telling her story about a space girl going to the Moon, she mentioned that the space girl would see lots of planets from the Moon. The subsequent direction of Sally's interview resulted in her revealing an interesting idea about the Earth:

Interviewer: Yes, What do you think Earth would look like if you were standing on the Moon?
Sally: A circle and then the thing inside it.
Interviewer: The thing inside?
Sally: Ah hum [affirmative].
Interviewer: What's inside?
Sally: Australia.
Interviewer: Australia would be inside the Earth?
Sally: Yes.
Interviewer: … Do you think you could see Anna [Sally's sister]?
Sally: Mm [affirmative].
Interviewer: Why?
Sally: Because she's down there.

This excerpt from Sally's interview indicates that she had a view of the Earth referred to by Vosniadou (2003) as a 'hollow sphere' where children see the Earth with people living on flat ground deep inside it, or a flattened sphere with people living on its flat top and bottom.

Theme 2: Creatures and Artefacts

Seven of the ten children talked about creatures and artefacts they associated with the Moon including "space people," "space guys," "aliens" and "astronauts" as well as human technology or artefacts that would enable people to travel to the Moon including "rockets",

"planes", "space suits" and a "jet pack". For example, Sally (AUS, 6) explained that space people go to the Moon in rockets and that they "float" on the moon.

Interviewer: What else do you know about the Moon, Sally?
Sally: Rockets come on it.
Interviewer: Rockets come on it, yes. How do you know about rockets?
Sally: It's big. And they blow fire out of it and they come apart.
Interviewer: Yes, did you see that somewhere? It coming apart?
Sally: On T.V.

When Sally was asked to construct a story about the Moon she talked about a "space girl" who was always drawing pictures of the Moon and when she grew up she became a "space girl" and, "She went up in the rocket and went floating on the Moon" and, "She saw lots of planets." Sally's mother, Janet, explained that Sally had recently seen rockets on the television news and that she had made a "picture of a space man recently at school." Sally's mother was able to find the picture of an astronaut in the file of Sally's school work that she kept. The picture was made from pieces of paper and the students had to write a sentence underneath the picture. When the interviewer asked Sally about the picture she explained that spacemen, "they float," and that the spaceman she made has a tube, "so he can breathe," and that he needs it, "because he'll die," and agreed with the interviewer that there is no air on the Moon.

When asked how someone could get to the Moon, Steve (AUS, 5) also mentioned rockets.

Interviewer: If you went to the Moon, how would you get there?
Steve: Rocket.
Interviewer: A rocket?
Steve: And in a plane.
Interviewer: Yeah? What do you know about rockets?
Steve: They have fire coming out of it.
Interviewer: How do you know about that?
Steve: Because I saw a rocket.

There was a discussion with Steve's parents, Tara and Ray, about Steve's experiences of rockets and Ray confirmed that Steve had seen an, "air show with a whole lot of other planes come over and they had jets… and launching rockets." Tara also explained that "It could have been at school reading a book. They're showing pictures of rockets and all that sort of stuff. And this term they actually had to paste a rocket together." After the interview, Tara was able to locate the rocket activity that Steve had completed at school. It was a shape activity where Steve had been required to cut out shapes to make up the rocket.

Rick (MN, 5) spoke of space aliens:

Interviewer: Tell me about the Moon up in the sky.
Rick: There's space aliens up there… But there's some guys that live on the Moon. They're space guys. And those aliens live on some other moons…The Moon is ours—the orange one. That's where space aliens live and some others … on other moons. Some people go on our Moon and some people go on aliens' moons.
Interviewer: How do those guys get up on the Moon?
Rick: They put … a jet pack on.

Later during the interview, while Rick was telling his story, he elaborated further on this point by saying "The blue Moon is ours…other colored ones are the space aliens' ones." It

is not uncommon for children to express the idea that there are many suns and moons (Piaget 1929). Rick has constructed two or more moons which are each occupied by either people or aliens. During the interview with Rick's mother, she related how they often go to *The Space Aliens Restaurant*, a local restaurant which displays planets and pictures of aliens overhead. It seems that pictures and posters of space aliens in the Space Aliens Restaurant were involved in Rick's belief that there is *our* one Moon but also *other* moons on which aliens live.

Rick's story was as follows:

> There were space aliens gathered up on the Moon. Guys came up. The aliens took them away. Then a space tiger came up and went after the aliens. It bit the aliens' legs. Then the guys were alive.

During the interview, Ellen's mother stated that she had no recollection of any books that Ellen (TX, 6) might have read concerning the Moon and sky. However, Ellen explained that she had read a book in kindergarten about the Moon and talked about "flying to the Moon," a space "suit," and a "spaceship."

> Interviewer: Oh yeah? Do you remember the name of it?
> Ellen: Uh … "Zoom, Zoom, Zoom, I Am Off to the Moon."
> Interviewer: "Zoom, Zoom, Zoom, I Am Off to the Moon"! What's that one about?
> Ellen: It's about this kid who was flying to the Moon and he was acting like he was in space.
> Interviewer: Uh-huh?
> Ellen: And he had this big …um … space suit on, and at … yeah … but …and he put on a buckle and he acted like he was in a spaceship.
> Interviewer: Oh yeah? So did he get to go to the Moon?
> Ellen: Uh-huh.

"Zoom! Zoom! Zoom! I'm Off to the Moon" (2002), was written by Dan Yaccarino. In this story, a boy becomes an astronaut and rides a spaceship to the Moon, lands on its surface, collects rocks, and drives a Land Rover. He returns to Earth with much celebration.

Theme 3: Animism

Piaget (1929) described the phenomenon of *animism* when a child "will regard as living and conscious objects which are for us inert" (p. 169) and further elaborated on the way he uses the word to mean "the tendency to regard objects as living and endowed with will" (p. 170). Of the ten children interviewed as part of this study, eight said that the Moon is not a living thing and the remaining two said it is a living thing. Excerpts from the interviews with the children presented below reveal the reasoning they used.

Ellen (TX, 6), who stated the Moon is not alive, seemed to represent the Moon with animistic characteristics in her 'true' story as she described the Moon first moving with her friend, and then traveling to somebody else's house after her friend's door closed, as if it had feelings of rejection and went searching for a new friend. She continued this pattern of describing how the Moon moved either with her or a friend.

> One time I saw a friend … out the window, and I saw it [the Moon] moving too. I mean, I saw it moving with him and um, he was going to his house. When he shut the door, the Moon, he didn't see the Moon. And then he went to his room. The Moon, then it went to somebody else's house.

The Moon's role in her story (as best supporting character) seemed similar to that of a dog's role in the numerous stories involving a child and a dog (e. g. Naylor's 1997 book, "Shiloh"; Hoffman's 2003 story, "Good Boy"), where the story might begin with the dog following a child home. However, Ellen never used the word 'following' within her story; she stated, "I saw it (the Moon) moving with him". Ellen, herself, was a character/narrator of her story as she reported the events that she said were true because she observed them from her window. From that point on in her interview, this idea of the Moon's moving seemed to take on some significance.

Interviewer: Okay, um … did it look like it was moving?
Ellen: Uh-huh.
Interviewer: It did? How did that happen?
Ellen: When you're … when you move the car it moves … too.
Interviewer: When you're in the car it moves too? And so, can it follow you?
Ellen: Uh-huh.
Interviewer: Okay. Why does it do that?
Ellen: Um … I don't know.

Even though Ellen stated that her story is true, and gave the Moon animistic characteristics, she stated earlier in the interview that the Moon is not alive because it does not have a mouth, eyes, or nose. In the following excerpt from an interview, Winnie (MN, 6), expressed the idea that the Moon gets smaller by shrinking.

Interviewer: What did the Moon do when you were out?
Winnie: It got small.
Interviewer: How does it do that?
Winnie: By shrinking.

During the parent interview, we discovered that Winnie's parents had read "Papa, Please Get the Moon for Me" (Carle 1986) to her. In this book, a child asks her father to get the Moon for her. Pictures show the Moon in its full phase and then in progressively *shrinking* phases until it is a thin crescent and small enough for papa to take back to the Earth to his daughter. Winnie's experience with this story may have influenced her response.

Winnie's older brother, Eric (MN, 7), had a more detailed picture of his natural world than Winnie. When asked, "Does it look like the Moon is moving?" he replied, "It's actually just in one spot." This could be taken as a pure and simple refutation of animistic lines of thought. However, one and one-half minutes later in the interview, the following exchange took place.

Interviewer: Could the Moon follow you?
Eric: No… because it couldn't walk all around the world… One half the world would be daytime and the other half would be night time.

This response could be interpreted as a purely logical comment reflecting the more advanced, non-animistic line of thinking. It is logical, because it implies that night contradicts day and they can't coexist in the same place, therefore, the Moon couldn't follow him. On the other hand, children often repeat what they hear from adults without fully comprehending the implications. Also, the first part of Eric's remark (above) could be taken as animism. He says "It [the Moon] couldn't walk all around the world" and thereby implies that the Moon has the ability to do things on its own (such as walk). Is this only metaphorical language or does it reflect animistic thought? Shortly after this exchange during the interview, the researcher asked Eric, "How do you know that?" and he replied

"[I]read it in a book. My dad told me, too." Later during the interview, Eric was asked "Where does the Moon go when you can't see it?" He answered:

> The Moon goes to the other side of the world. It's like a person running across the whole world. One half is night, the other half is day. The Moon would have to be running all night to get to the other side, then running to the other side.

The researcher followed up on these comments by saying "That story you told me about the Moon running. Does it really happen like that?" and Eric answered "No." We take this as evidence that Eric's language is metaphorical rather than expressive of animistic thinking.

When Lizbeth (OH, 6) was shown pictures of the Moon and asked if she recollected having ever seen the Moon look like those in the photos, she replied that she had seen both:

> Interviewer: So why does the Moon sometimes look like this [waxing crescent] and why does it sometimes look like that [waxing gibbous]?
> Lizbeth: Maybe sometimes it's happy and it looks like the Sun [waxing gibbous], and sometimes it's grumpy and it looks like this [waxing crescent].

While Sally (AUS, 6) said the Moon can move because "it floats" she said it is not living because it "doesn't have a face on it."

> Interviewer: Do you think the Moon sometimes moves?
> Sally: Yes.
> Interviewer: How does it move?
> Sally: It floats.
> Interviewer: Okay. Do you think the Moon is alive?
> Sally: No.
> Interviewer: No, why not? [pause] Can you tell me something that is alive? Are you alive?
> Sally: Yes [laughter].
> Interviewer: Yes, is Mia alive, your cat?
> Sally: Yes.
> Interviewer: So why isn't the Moon alive?
> Sally: Because it doesn't have a face on it.
> Interviewer: Oh because it doesn't have a face. Mm. Have you got a face?
> Sally: Yes.
> Interviewer: Do all alive things have faces? [Sally nods]. Mia's got a face hasn't she? [Sally nods and laughs]. Yeah. Sometimes in books I see a Moon that has a face on it. Do you think that's real, or not real?
> Sally: Not.
> Interviewer: It's not real. So how did the Moon get a face in the book?
> Sally: Because they just painted it on.
> Interviewer: Who did that?
> Sally: The author or somebody.

Steve (AUS, 5) also said the Moon is not alive "because it can't talk" and it isn't alive like his dog "because she's jumping". Sally and Steve were both confident that the Moon isn't a living thing. This indicates a lack of childhood animism, that is, they did not have the simple belief that all things that can move are alive. Both children owned pets (Sally a cat and goldfish and Steve a dog and goldfish). It is possible that this cultural factor may contribute to the children having a relatively sophisticated idea about living animals.

Theme 4: Permanence

Robyn (OH, 8) revealed her understanding that the Moon is sometimes hidden from her view when, and only when, it is raining.

> Interviewer: Is there a time sometimes when you can't see it [the Moon]?
> Robyn: Oh yeah, when it's raining.
> Interviewer: So sometimes it's raining and you can't see it? Well, is there a time when it's not raining and you can't see the Moon?
> Robyn: No.

Robyn seemed to believe that the Moon remains in the portion of sky visible to her but the Moon is only blocked from her view whenever a cloud passes between the two of them. As explained in the literature review, several studies described young children using a 'blocking' notion, such as clouds covering the Moon, to explain why the Moon's appearance changes. For young, first grade children Haupt (1950) found 61.9% of the children stated they did not know and 19% claimed cloud coverage.

Similarly, when asked where the Moon goes when you can't see it, Sally (AUS, 6) indicated that clouds can block our view of the Moon. She also indicated her non-scientific belief that the Moon can always be seen in the sky and the only reason we can't see it is if it's blocked by clouds. When looking at a picture of a crescent shaped Moon, Sally said the shape was caused by the Moon going down into the clouds.

> Interviewer: Do you want to look at some of those pictures? See this shape, do you see that sometimes?
> Sally: Yes.
> Interviewer: What makes it that shape?
> Sally: Um, cause it's going away.
> Interviewer: Where's it going?
> Sally: Down.
> Interviewer: Where's it going down?
> Sally: [Pause] Into the clouds.

In response to a similar question concerning where the Moon goes when you cannot view it, Lizbeth (OH, 6) reported that "the Moon goes down…under somewhere else on the Earth". Susan (MN, 6) expressed the ideas that the Moon is "something in Earth" and "part of the Earth."

> Interviewer: The Moon—would you say it's alive or that it's something that's not alive?
> Susan: It's alive. It's a thing … because it's something in Earth.

For her story about the Moon, Susan said:

> Once upon a time, the Moon was bright and also the Moon was fun to look at it, and it was part of the Earth. The end.

It is not clear what Susan meant when she said that the Moon is "part of the Earth." During the interview with her parents, Susan's father identified an experience that he thought might have influenced these comments. He said, "We saw an eclipse—the shadow of the Earth on the Moon." It was his opinion that Susan's ideas about the Moon were tied to her recent experience of observing an eclipse. Since the Earth's shadow can obscure one's view of the Moon, it is "something in Earth." In addition to this experience, Susan and her mother

confided during the interview that they often read together a "little bear" story. One story, "Little Bear Goes to the Moon" (Holmelund Minarik and Sendak 1985), is about a young bear who decides to take a trip to the Moon. Upon his arrival, he discovers that the Moon is just like Earth. However, the story that her mother often read with Susan was a different one. After conversations with Susan's teacher, we discovered that Susan had been exposed to the text in question during her kindergarten year. It may be possible that Susan's comments were related to the similarity between the Earth and the Moon conveyed through this story.

Rick (MN, 5), was asked during his first telling of a story about the Moon, where the Moon goes when it "goes down." He responded "into the ground." Vosniadou and Brewer (1990) found that American children show a preference for thinking that the Sun goes down underneath the Earth while Greek children explained this phenomenon as the disappearance of the Sun behind the mountains or the sea.

Steve (AUS, 5) initially said that the Moon can move, but also said it looks like it can follow you. Later in the interview when asked where the Moon goes when he can't see it in the sky, Steve initially said, "I don't know," but after being prompted by the interviewer asking, "Does it go up or down or where, where does it go? responded, "It goes up… to space." While Steve indicated that the Moon "goes up" this may have been prompted by the interviewer's question. Steve's parents, Tara and Ray, elaborated on Steve's thoughts, experiences and expressed perceptions of the Sun and the Moon moving in the following way:

> Ray: Yes, when you said, "Where does the Sun go?" Or, "Where does the Moon go?" He usually says, "It goes to England". If you said, "What happens when night time comes, where does the Sun go?" He'd say, "Oh it goes to England."
> Interviewer: And that's, have you got any relatives?
> Tara: We've got relatives in England and Mum's [on holiday] over there at the moment.
> Interviewer: Okay, so he knows, so what happens, like if you ring her up, do you say it's night time there?
> Tara: Yes.
> Ray: When we're watching the cricket as well… So we'll be sitting here at night time watching the [direct telecast] cricket, and he'll say, " Where's that, Dad?" And I'll say, "England", and okay so they're playing in England, so the Sun's over there.

Sally's mother, Janet, also explained that Sally (AUS, 6) had some understanding of the time difference between Western Australia and New Zealand (5 h difference) because they had relatives living in New Zealand: "She understands that because if we're going to ring, we say, oh they're so much further ahead of us."

Discussion

The children who participated in this study provided us with a kaleidoscope of ideas about the Moon and the social and cultural experiences that influenced their ideas about the Moon. In the following discussion we have drawn primarily from the theoretical perspective of Brown (2010) and Brown and Hammer (2008) to enable us to view the findings about the children's ideas about the Moon as a complex dynamic system with many nodes and interconnections. We make the assertion that the themes that emerged in

the process of our research represent an initial set of *knowledge nodes* of the complex dynamic system of knowledge about the Moon. These knowledge nodes include: 1. The children's ontological ideas about the Moon; 2. The children's understandings about the Moon being animistic or non-animistic; 3. The factors the children associated with the Moon and, 4. The children's understanding of the permanence of the Moon. Figure 1 presents a schematic representation of the complex dynamic system of knowledge about the Moon that emerged from the findings and in the following paragraphs we discuss the beliefs, presuppositions, mental models (Vosniadou et al. 2008), and phenomenological primatives (p-prims: diSessa 1993) that could be considered part of the system.

Some of the ontological features of the Moon mentioned by the children during interviews included the shape, size, colour, surface texture ("has holes in it"), distance, the number of moons, and that the Moon is in "space" or "floating." We have represented these ideas in Fig. 1 as part of a node called *ontology* that forms part of the complex dynamic system of knowledge about the Moon. Each child was able to express ideas about the ontology of the Moon, however, each child had their own idiosyncratic network of ideas that represented the way they viewed the basic nature of the Moon. For example, most children mentioned the shape of the Moon, some said it is "round", others said a "circle". Children had different ideas about the colour of the Moon, one said "yellow" another said "orange," and one even said "blue".

With regard to what the children thought the Moon was made of, Lizbeth and Sally both said they didn't know what it is made of, but Lindsay said the Moon is made of snow. This was consistent with the environment in which she lived where snow and ice were commonplace. Steve, being an Australian and having never seen snow, had a different idea. He thought the Moon is made of plastic, which is a sensible idea considering his cultural experiences of a shiny, yellow cricket bat. He readily altered this view to the idea the Moon is made of rocks when he was given close up pictures of the Moon. Piaget (1929) interviewed an eight and a half year old child, Giamb, who also said the Moon is yellow. Piaget noted it "is true that in winter smoke has a yellow-greenish tint" (p. 275). He also noted that "these explanations are very interesting because of their spontaneous characters, they start from true observations" (p. 275).

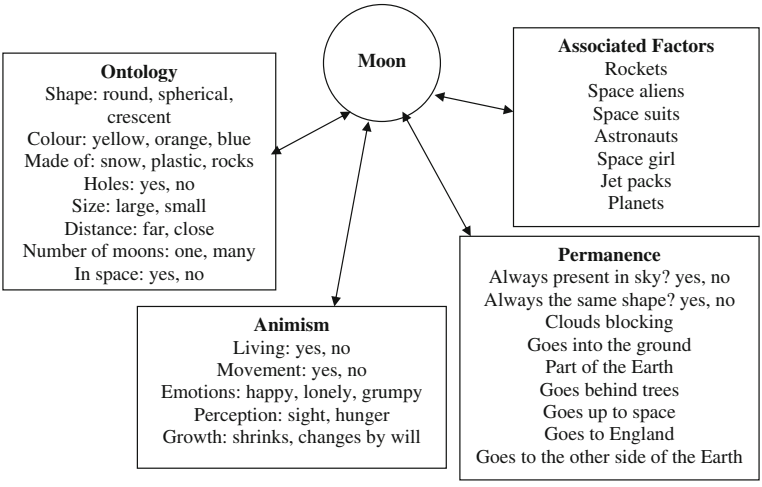

Fig. 1 A diagrammatic representation of the four main nodes that make up the complex dynamic system of children's knowledge of the Moon that emerged from the data collected in this study

We agree with Piaget that many of the children's ontological descriptions of the Moon seem to originate from observations and, from a child's perspective, subsequent logical thinking. We assert that the children generated a mental model (Vosniadou 1994) of the Moon on the spot for answering questions during the interview. This mental model enabled the children to visualize the shape, colour, texture, size etc. of the Moon. The ideas are interrelated and co-exist and they form, for the children, a mental picture of the basic nature, or ontology, of the Moon. In these ways they seem to form a coherent, but dynamic mental model (Vosniadou 1994).

The children associated a number of factors (creatures and artefacts) with the Moon including a "space girl," "space guys," "rockets," and a "space ship." We have represented this theme in Fig. 1 as a node called *associated factors* in the complex dynamic system of children's knowledge about the Moon. Some ideas expressed by the children would be valued from a scientific point of view. For example, the idea that rockets go to the Moon is accurate and there was evidence in the findings that some children had developed this idea from watching the news on television. Other ideas expressed in the interviews about factors associated with the Moon, such as "aliens" and "jet packs" were less scientific and seemed to us to represent something akin to diSessa's (1993) p-prims because they were culturally acquired fragments of knowledge that are naïve and incoherent. For example, Rick had seemed to acquire his ideas about space aliens living on the Moon from pictures on a wall at a local restaurant. At times, Rick seemed to contradict himself about whether space aliens lived on "our Moon" or only on other moons, indicating a degree of incoherence.

We did not find any evidence that the children in this study conceived the Moon as needing support from some structure in order to prevent it from 'falling down' as would be expected if children's ideas were constrained by physical presuppositions such as 'things fall down when unsupported.' While we did not ask any direct questions related to this topic, Sally described the Moon as "floating" in space and said that people need a rocket to get to the Moon. Steve also said we need a rocket or a plane to get to the Moon, Rick suggested a "jet pack" and Ellen described a kid flying to the Moon, talked about a "spaceship" and said the Moon is in "space". These ideas clearly indicate that the children were aware that there is space between where we are on Earth and where the Moon is. Moreover, their ideas about rockets and jet packs indicate they understood that we would need some device that would take us through space to get to the Moon. The children we interviewed seemed to clearly express their conceptions that the Moon is something that defies their Earthly experiences of gravity and that it is suspended in some place away from where we are located.

These observations indicate a connection between the ontological node (Fig. 1) and the associated factors node (Fig. 1) that we have included in our representation of the complex, dynamic system of children's knowledge about the Moon (Fig. 1). Being in space is an ontological characteristic of the Moon that most of the children in our study expressed. Their commentary about the associated factors such as rockets and jet packs, supports and confirms this ontological understanding that the Moon is located in space, is unsupported and far away from the Earth. As suggested by Brown (2010) and Brown and Hammer (2008), we have collected evidence that there are interconnections between the nodes in the complex dynamic system of knowledge.

Within the third theme presented in the findings we provided evidence that both did and did not support the notion that children may have animistic ideas about the Moon. We felt that the issue of animism was an important aspect of our proposed complex dynamic system of knowledge about the Moon and have thus included *animism* as a node in Fig. 1. For example, Sally, Ellen, and Steve, all said that the Moon is not alive and gave relatively

good reasons, for example, it doesn't have a face, doesn't talk, and doesn't scratch. Other children clearly indicated animistic ideas. Ellen for example, while saying the Moon isn't alive, also said that the Moon could go to someone's house, and Winnie, said that the Moon can shrink (i. e. the Moon has will). Stories that the children had read with their parents seemed to have influenced these young children and were consistent with animistic conceptions of the Moon.

It is interesting that from a scientific perspective, the Moon does indeed move in orbit around the Earth. This movement is not readily perceived by young children, however, and can only usually be deducted by careful observation of the position of the Moon in the sky at the same time every day. So why is it that some children do have animistic ideas about the Moon, some do not, and some seem to be very clear that the Moon is not alive but does have some animistic qualities such as a will and movement? While these ideas seem to be difficult to explain and difficult to understand from an adult perspective, our methods of working with the children's parents provided examples of each child's social and cultural environment that helped to develop a more detailed picture to explain the child's views. We discovered that Sally, Steve, and Ellen had pets, and it was clear to them that the Moon did not behave like their dog or cat and hence was not alive. On the other hand, Lizbeth had a pet dog and horse, but she thought the Moon is alive and that it can move at will. Our findings raised questions about children's experiences with pets and whether there is a relationship with the degree to which they attribute animistic qualities to objects. Further, Winnie and Ellen had been read stories about the Moon where the Moon had behaved in animistic ways and their conceptions of the Moon had possibly been influenced by these stories.

The findings presented under the theme of permanence also indicate the wide range of ideas about the Moon held by the children who participated in this research. The theme of permanence embraced two issues. The first issue is whether the Moon always exists in the sky, that is, is it a permanent physical body and, if we can't see it in the sky; why can't we see it, or where does it go? The second issue is related to the different phases of the Moon, that is, is the shape of the Moon permanent, or does it change and, if it does change, why and/or how does it change? These are complex issues, even for older people. The issues about permanence emerged as an important theme in the findings and thus we have included a *permanence* node in the complex dynamic system of knowledge about the Moon in Fig. 1.

Sally and Robyn both thought that the Moon is permanently in the sky unless it is blocked by clouds. Susan, and Steve, in contrast, said that the Moon moves, "down into the Earth," and, "up to space" respectively. All children agreed that the Moon is sometimes not visible and they all drew on various explanations that may have helped them to understand this phenomenon in a way that was logical to them, that is, that vision of the Moon is either blocked by another physical object, or it has moved to a place where it cannot be seen. Both these ideas are consistent with physical explanations and could be considered to be constrained by a presupposition (Vosniadou 1994) about physical permanence. It is interesting that it is not the movement of the Moon that makes the Moon not visible during the daily cycle (as some children seem to think), but the rotation of the Earth. Children, however, cannot perceive that the Earth moves, so it is more logical for them to say that the Moon moves. The observation of the Moon setting below the horizon also seems to be consistent with some children's explanations that the Moon has gone "down into the Earth."

Limitations of this Research

This research has been conducted in the interpretive paradigm (Mertens 1998). Accordingly, we collected detailed, qualitative data in the participants' settings, we

analysed the data inductively, building from particulars to general themes, and then we interpreted the meaning of the data to build a theoretical model of a complex dynamic system representing children's knowledge of the Moon (Creswell 2009). Consistent with an interpretivist approach, we focused on individual meaning and the importance of rendering complexity and make no claims about the statistical generalisability of our findings. A collection of multiple case studies, however, may help to shed further light on other cases. Stake (2006) supports this approach by claiming that a collection of cases that are bound together by a common theme—a *quintain*—can be subjected to cross case analysis for improvement of conceptualization and theory. While each case is unique, commonalities as well as differences can be informative. It is in this spirit that we approached identification of themes across the ten case studies and developed the model presented in Fig. 1. Importantly, we encourage exploration, critique and/or elaboration of our model through further research with children of different ages and cultures.

Conclusion: A Complex Dynamic System of Children's Knowledge About the Moon

Our case studies, developed from in-depth interviews with young children and their parents, add to the complex picture about how rich social and cultural environments impact on children's ideas. The participating children's ideas about the Moon were not completely consistent with a framework theory view of knowledge (Vosniadou 1994), nor were they completely consistent with a knowledge in pieces perspective (diSessa 2008). We found the complex dynamic system view of children's knowledge proposed by Brown (2010) and Brown and Hammer (2008) an elegant, comprehensive, and accurate way to represent our findings. The children's ideas could be represented under four knowledge nodes within the complex dynamic system, including ontology, animism, associated factors, and permanence. Each child's complex dynamic system of knowledge about the Moon included each of these nodes, however, their understandings within the nodes were idiosyncratic. The knowledge within each node was found to include ideas that could be described as mental models, phenomenological primatives (p-prims), and presuppositions. The nodes within the complex system were demonstrated to be interconnected and the knowledge also was shown to be dynamic. A consistent finding was that the children's idiosyncratic ideas could be explained by their environment, sometimes their ideas were influenced by observation of physical factors in their environment, sometimes they were influenced by social interaction or cultural activities.

Appendix 1: Interview Protocol for Children

Semi-structured interview protocol; i.e., ask follow-up questions based on what the child tells you, but anticipating these topics.

Part I. Aim: To ascertain the childs' general conception of the Moon

1. [After introductions which include questions about the child's name and age] Have you ever been for a walk outside at night?
2. [If "no" to question above] Have you ever been for a drive [or a walk outside] at night?
3. [If "yes" to either question above] Where was the Moon? [If no specific response is given] Was the moon in the sky?

4. Can you tell me anything about it?
5. [If no response to above question] Did you notice anything about it?
6. [If "no" to question above] Did it look like it was moving?
7. How does that happen?
8. Can it follow you?
9. [If "yes"] Why does it do that? [Or, if "no"] Why not?
10. Has anyone else talked to you about these things? [If "yes"] What did they say about it?
11. [If child says that the Moon can follow you] Can it follow two people at the same time? [If "yes"] What if you went this way [point one direction] and I went that way [point the opposite direction]. Which one of us would it follow? Why?
12. Is the Moon alive? How do you know?
13. Is there more than one moon?
14. [If "no" to 11, above] Why not? [Or, If "yes"] Tell me more about that!
15. [If "yes" to above] How many moons are there? How do you know?
16. How did the Moon begin? Do you have any ideas?
17. Where does the Moon go when you can't see it?

Part II. Aim: To get a picture of the child's concept of "story" (Arthur Applebee, L. Vygotsky,. J. Bruner, J. Piaget)

18. Can you tell me a story about the Moon? [Alternates: Do you know any stories about the Moon? Could you make up a story about the Moon?]
19. [Alternate to #1, above] Using pictures or picture storybooks that show the Moon from different perspectives/viewpoints, show the pictures to the child and ask the questions in #1, above.

Part III. Aim: To shed light on the child's ability to cognitively distinguish between fact and fiction/fantasy with regard to story

20. That story you just told me… Did it really happen? [Alternate: Is it what really happens?].
21. What really does happen?
22. How do you know?

Part IV. Aim: To shed light on the child's ability to cognitively distinguish between fact and fiction/fantasy with regard to interview

23. When I first started to ask you questions today, and you answered them for me, did you tell me what really happens?
24. [If "yes"] How do you know it really does happen? Where did you learn this?
25. [If "no"] What really does happen?

Appendix 2: Interview Protocol for Parents

After interviewing the child, ask parents to volunteer any insights they might have about the child's experiences that may have influenced his or her ideas. Specifically, include questions such as:

26. Can you recall any time recently when s[he] talked about the Moon with you?

27. About when [how old was he or she] when s[he] started to talk about these things?
28. Have you shared any experiences together [e. g. holidays, camping, outdoor events] in which you discussed related topics?
29. Have you discussed *other* science-related topics together?
30. What books have you read to your child that relate to this topic?
31. Do you know if your child has learnt anything at school/kindergarten about the Moon?
32. [If relevant include questions about religious influences e.g.] Do you discuss religious ideas with them?

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