International Journal of Science Education, Part B
Communication and Public Engagement

ISSN: 2154-8455 (Print) 2154-8463 (Online) Journal homepage: http://www.tandfonline.com/loi/rsed20

Using a planetarium fieldtrip to engage young children in three-dimensional learning through representations, patterns, and lunar phenomena

Julia D. Plummer & Kim J. Small

To cite this article: Julia D. Plummer & Kim J. Small (2018): Using a planetarium fieldtrip to engage young children in three-dimensional learning through representations, patterns, and lunar phenomena, International Journal of Science Education, Part B, DOI: 10.1080/21548455.2018.1438683

To link to this article: https://doi.org/10.1080/21548455.2018.1438683

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, PART B, 2018
https://doi.org/10.1080/21548455.2018.1438683

Using a planetarium fieldtrip to engage young children in three-dimensional learning through representations, patterns, and lunar phenomena

Julia D. Plummer [a] and Kim J. Small[b,c]

[a]Department of Curriculum & Instruction, Pennsylvania State University, University Park, PA, USA; [b]Department of Chemistry & Physics, Arcadia University, Glenside, PA, USA; [c]Sandy Run Middle School, Upper Dublin School District, Maple Glen, PA, USA

ABSTRACT

Fieldtrips to informal science institutions can be opportunities for children to engage in three-dimensional learning, which is the integration of core disciplinary ideas, science practices, and cross-cutting concepts. We explored the question of whether the combination of a planetarium fieldtrip and classroom lessons could support young children's three-dimensional learning in astronomy. We assessed first grade students' (6–7-year-olds; $N = 46$) three-dimensional learning at the intersection of lunar phenomena, representational practices, and patterns. Students' were interviewed, where they both described their understanding verbally and constructed representations, before the intervention, after the intervention, and one year later. A mixed-methods analysis demonstrated significant improvement in students' three-dimensional learning, focused on the apparent daily motion of the Moon and lunar phases. Analysis of both interview results and audio/video of the intervention suggest that the planetarium fieldtrip provided students with a source of evidence for concepts and patterns related to scientific phenomena, which was then the subject of further inquiry in the classroom as students integrated new science concepts and patterns with their own ideas for how to create scientific representations. These findings suggest that fieldtrips, when supported by students' classroom experiences, can serve an important role in engaging young children in three-dimensional learning and thus pointing to ways that informal science venues can work with formal educators to engage students in doing science.

ARTICLE HISTORY
Received 4 November 2016
Accepted 6 February 2018

KEYWORDS
Elementary; astronomy; science practices; planetarium; fieldtrips

Introduction

Though engaging children in science through scientific inquiry has been the goal of the science education community for many decades, recently the *Framework for K-12 Science Education* (*Framework*; National Research Council [NRC], 2012) presented a new emphasis on children learning science through the integration of disciplinary core ideas, science practices, and cross-cutting concepts; this integration is referred to as *three-dimensional learning*. Through engagement with three-dimensional learning, 'students build an integrated understanding of a rich network of connected ideas. The more connections developed, the greater the ability of students to solve problems, make decisions, explain phenomena, and make sense of new information' (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014, p. 2). The focus on three-dimensional learning pushes us to move away from

CONTACT Julia D. Plummer jdp17@psu.edu Pennsylvania State University, 149 Chambers, University Park, PA 16802, USA
Supplemental data for this article can be accessed https://doi.org/10.1080/21548455.2018.1438683

viewing science content and inquiry as separate pieces in order to help children learn to apply their knowledge in context and reflects the ways in which scientists carry out their work. Further, engagement in the fused dimensions of disciplinary core ideas, science practices, and cross-cutting concepts is mutually reinforcing; children need to learn through these dimensions to gain proficiency in all (Krajcik et al., 2014; NRC, 2012).

Informal science institutions (ISIs) have the potential to support young students and their teachers in three-dimensional learning. *Learning Science in Informal Environments* (NRC, 2009) advocates for ISIs—such as museums and planetariums—to be venues supporting science learning through engagement across science practices, disciplinary core ideas, and cross-cutting concepts. Yet, the literature has yet to fully address how a fieldtrip to an ISI can support students' three-dimensional science learning. Instead, prior research on fieldtrip learning has often focused on how students learn about content or how their attitudes towards science change (DeWitt & Storksdieck, 2008). This leaves a gap in our understanding of the role fieldtrips might play in addressing the education of young learners from a holistic standpoint, as articulated in the *Framework*'s depiction of three-dimensional learning for science achievement.

Therefore, we investigated how a fieldtrip to a planetarium, and two associated classroom lessons, supported first-grade students (6–7-year-olds) as they integrate aspects of three-dimensional learning. Guided by the *Framework* and the *Next Generation Science Standards* (NGSS Lead States, 2013), we selected elements of three-dimensional learning that could be supported in a planetarium fieldtrip and linked classroom lessons for this age-level. We selected a conceptual focus on lunar phenomena (phases of the Moon and daily apparent motion of the moon) from *The Earth and the Solar System* disciplinary core idea. We selected the cross-cutting concept of *patterns* as this aligns to the repeating nature of the Moon's daily rising and setting and monthly change in appearance. And from the science practice dimension, we focused on *modelling* through the development of drawn representations. The study was guided by the following research question: How did students' three-dimensional learning of lunar phenomena change from before to after a planetarium fieldtrip and associated classroom lessons?

We took this focused approach on how to address these three dimensions because (a) we are addressing learning that takes place through a fieldtrip experience and (b) we are focusing on young children's early experiences learning science through informal and formal settings. More research is needed that helps us understand how to enact three-dimensional learning. However, the apparent pattern of the Moon's daily motion and monthly change in phases aligns well to the goals suggested by the U.S. *Next Generation Science Standards* for students to learn in first grade (NGSS Lead States, 2013). These phenomena represent appropriate starting points for early elementary students that could lead to more sophisticated explanations of celestial motion as they continue to study astronomy in later grades, moving towards a full understanding of the disciplinary core idea.

Young children's understanding of these phenomena has been previously described (Plummer, 2009a; Hobson, Trundle, & Saçkes, 2010) and we have evidence that kinaesthetic strategies support conceptual learning for young children in the planetarium (Plummer, 2009b). This existing research base allows us to now turn our attention to how to best integrate methods of shifting conceptual learning into three-dimensional learning, by including children's engagement in science practices and cross-cutting concepts. Our new research considers how a planetarium fieldtrip, in combination with classroom lessons that support the fieldtrip experience, can engage learning of these three dimensions together. In this way, our research can add to the field's understanding of how to design fieldtrips that support young children's learning.

Conceptual framework for fieldtrip design that supports learning

Extensive research has examined the variables that influence student outcomes from fieldtrip experiences (e.g. DeWitt & Storksdieck, 2008; Rennie & McClafferty, 1996). Such research supports the notion that, despite the brief duration of most fieldtrips, these experiences have a positive impact on student learning (Anderson, Lucas, & Ginns, 2003; Gutwill & Allen, 2012; Plummer, 2009a). While some studies have examined learning within a week or so of the students' visit, other studies have looked for evidence of long-term impact on student learning. Using a stimulated recall approach with elementary-age students both one-week and 10–12 weeks after a science center visit, DeWitt and Osborne (2010) found the fieldtrip was highly memorable as students were able to apply their understanding of science to explain the exhibits. Bamberger and Tal (2008) interviewed middle school students both immediately after and 16 months after a visit to a science museum. When responding to the delayed post-interview, students retained details of their visit, demonstrated ways the visit impacted their understanding of science, and made connections with both their in-school and out-of-school knowledge. Miglietta, Belmonte, and Boero (2008) gave a content-based questionnaire to elementary through high school students before, immediately after, and three months after a visit to a marine biology museum. Though students did not maintain the same level of improvement, their delayed-test results were still significantly higher than their pre-visit responses. These studies point to the potential long-term impact that even brief fieldtrips to ISIs can have on student science learning; however, they do not explore the ways fieldtrips to ISIs can support students' engagement in three-dimensional learning.

Drawing on elements that support learning in informal environments provides a basis for designing opportunities that might have the potential to promote three-dimensional learning. Students learn more on fieldtrips when they are oriented to the nature of the fieldtrip and expected experiences (Anderson & Lucas, 1997; DeWitt & Storksdieck, 2008; Griffin & Symington, 1997). Anderson and Lucas (1997) found that prior visits to a fieldtrip site or participation in a pre-orientation program could reduce the novelty of the visit and in turn enhanced student learning. Thus, we might first consider that students need guidance or preparation for their out-of-school experience in our research design.

Research supporting a socio-constructivist approach to museum learning suggests that students engage actively in ways that go beyond a simple 'hands-on' approach; Hein (1998) emphasizes that activity refers to mental activity, which may or may not involve corresponding physical engagement. Moving towards active participation that engages students in making sense of their experiences at a fieldtrip setting requires a more structured as opposed to an unstructured experience (Bamberger & Tal, 2008; Griffin & Symington, 1997). And at the same time, a structured approach to a fieldtrip should avoid shifting towards a more didactic, lecture-style presentation as such an approach tends towards a passive experience for students rather than one that engages them with active exploration of phenomena (Cox-Petersen, Marsh, Kisiel, & Melber, 2003).

To build on students' experiences during the fieldtrip, several researchers have recommended a close connection between the fieldtrip and their classroom lessons (e.g. Anderson, Lucas, Ginns, & Dierking, 2000; Lucas, 2000; Storksdieck, 2006). Providing students with the opportunity to apply concepts learned on the fieldtrip will support their retention of new knowledge and provide additional sense-making opportunities with their peers (e.g. Anderson et al., 2000; Lucas, 2000). Additional minds-on applications in the classroom can improve long-term understanding of fieldtrip conceptual goals as well as depth and connections within the domain. Students need opportunities across multiple situations, engaging physically and socially, to support the long-term development of or revision to their mental models (Brown, Collins, & Duguid, 1989). Thus, pre-fieldtrip preparation and post-trip experiences may be necessary for long-term learning opportunities from fieldtrips (DeWitt & Storksdieck, 2008; Storksdieck, 2006).

Planetarium fieldtrips

While there is a long history of research on student learning in the planetarium (Brazell & Espinoza, 2009), recent research has considered both new methods of engaging students actively and how to effectively support learning through the combination of a planetarium fieldtrip and classroom activities. Active participation has its own specific challenges in the planetarium environment as students primarily spend their visit seated, focused either on the presenter or a program projected on the ceiling. Engaging students through their own kinaesthetic motions, to make predictions or represent the motion of celestial objects, has been found to improve early elementary students' understanding of celestial motion (Plummer, 2009a; Plummer, Kocareli, & Slagle, 2014). These studies align students' active engagement with the planetarium's central design to simulate celestial phenomena as seen from Earth.

A few studies have investigated how integrating a planetarium fieldtrip with classroom lessons can support student learning. Schmoll (2013) investigated U.S. 5th grade students engaged in a 15-day project-based astronomy unit, which allowed students to apply their planetarium observations to aid in constructing explanations in the classroom. Students used their observations in the planetarium as evidence for explanations about the Sun and Moon's apparent daily motion. Plummer et al. (2014) compared third grade students' explanations for the apparent daily motion of the Sun, Moon, and stars across three instructional conditions: classroom-only, planetarium-only, and a combination of planetarium and classroom instruction. Students who both visited the planetarium to observe the phenomena and then participated in classroom instruction made the most improvement in their ability to construct scientific explanations. The instruction took advantage of the planetarium's strengths in simulating astronomical phenomena while the classroom instruction provided support for students' constructing explanations based on their observations.

These studies suggest that methods are available to support active learning in the planetarium (e.g. Plummer, 2009a) and that fieldtrips to planetariums can work in conjuncture with classroom-based instruction to improve student learning in astronomy (Plummer et al., 2014; Schmoll, 2013). However, these studies did not explore how a planetarium fieldtrip, in conjunction with classroom curriculum, can be used to support students' engagement in the integration of the three dimensions of learning described in the *Framework*. This points to the need for research that explores new goals for planetarium fieldtrips.

Three-dimensional learning in early elementary science

The specific notion of three-dimensional learning—the fusion of disciplinary core ideas, cross-cutting concepts, and science practices—'describes not the process of learning, but the kind of thinking and understanding that science education should foster' (NRC, 2014, p. 1). As the notion of three-dimensional learning is relatively new to science education research, and few studies explore this construct, we review literature that has considered the fusion of content and science practice to orient our work.

Theoretical framework for three-dimensional learning

Three-dimensional learning represents a goal for students that challenges them to integrate conceptual understanding with an understanding of doing science to form a more coherent view of the world. As such, we drew upon socio-constructivist theory to guide our thinking about how instruction supports children's engagement in three-dimensional learning, because socio-constructivistism, grounded in Vygotskian theory of cognition and learning, considers how learners construct their understanding of the world while also emphasizing the importance of students' opportunity to collaborate and the nature of the social context. This allows us to consider how the learners' experiences are shaping their construction of three-dimensional learning. Learning occurs in the 'zone of proximal development,' where a learner is supported by a more knowledgeable educator or peer, allowing the individual or group to perform at a level beyond what they could alone (Vygotsky, 1978). Socio-constructivism is fundamentally a situated perspective on learning and knowledge in that both are developed through (Brown et al., 1989). Both social interactions and the physical environment shape the learning process (Brown et al., 1989; Nersessian, 2004). This perspective on the role of social, cultural, and physical environment reflects a situative perspective on knowing wherein '[analyses] of activity focus on processes of interaction of individuals with other people and with physical and technological systems' (Collins & Greeno, 2011, p. 65). Therefore, our understanding of how to support three-dimensional learning must consider how both the social context and physical environment contribute to this sense-making process of using evidence-based practices to negotiate meaning about phenomena, for young learners.

Potential for three-dimensional learning in early elementary grades

While the notion of 'three-dimensional learning' in science is relatively new (NRC, 2012), some recent literature suggests ways we might consider engaging early elementary students in three-dimensional learning across disciplinary contexts. These studies demonstrate the importance of engaging children with scientific phenomena, such as investigating animal behavior (Metz, 2004), states of matter (Varelas et al., 2008), or properties of water (Siry, Ziegler, & Max, 2012). However, such methods may be more challenging in the domain of astronomy where the phenomena are not always directly accessible for children. Astronomical phenomena common to elementary grades are often those that require investigation through systematic observation to identify patterns of change celestial objects' motion and appearance. This introduces specific challenges for engaging children in the authentic practice of scientific observation (see *Planning and Carrying Out Investigations*, NRC, 2012), including the long period of change (hours, days, or weeks) and difficulty in making some observations due to celestial objects' appearance in the night time sky or due to weather.

Because of these challenges, engaging students with second-hand investigations of phenomena may be necessary to engage children in three-dimensional science learning in the domain of astronomy. For example, Kallery (2011) studied 4–6-year-old Greek children engaged in a unit about the shape and movement of the Sun, Earth, and Moon. Children used photographs and videos as evidence as they developed representations of celestial objects and their motions and later developed models to explain the day/night cycle. Hobson et al. (2010) engaged U.S. children in a second-hand investigation of astronomy. Children from a combined 1st and 2nd grade classroom (7–9-year-olds) investigated the pattern and cause of lunar phases using a planetarium simulation on their classroom computer. Over several days of instruction, children gathered data through observations of the computer simulation, analysed their data to find patterns in lunar phases, and co-constructed a model to explain their observations with their teacher. Most children developed more sophisticated descriptions and explanations of lunar phases after instruction. These studies suggest that second-hand investigations, such as using data collected in a planetarium environment, show promise for improving young students' conceptual understanding and provide a context to develop their three-dimensional learning.

Our study focused on how the planetarium fieldtrip experience supported children's development of drawn representations for patterns in lunar phenomena. Developing representations is a fundamental element of authentic science practice (diSessa, 2004; Roth & McGinn, 1998). Thus, supporting children's development of representational competency across science domains is important; Danish and Phelps (2011) argue, 'young children are a crucial population to study because the early development of the practices of creating, modifying, and evaluating representations is important to supporting their later science and representational activities' (p. 2071). Further, engaging children in developing their own representations of phenomena can help them learn and remember (Schwartz & Heiser, 2006). In a study of U.S. kindergarten and 1st grade students (5–7-year-olds), Danish and Phelps (2011) found that children's representational practices became more sophisticated and nuanced as they developed a deeper understanding of the science content, showing the potential for integrating science content and practice in children's learning. As children engage in observing scientific phenomena, they can use this data to improve their representations. Drawing can also allow students to communicate complex ideas beyond their verbal abilities and reveal the nature of their understanding during instruction (Brooks, 2009; Papandreou, 2014). However, few studies have considered how a fieldtrip experience can contribute to students' development of representational practices, especially at this age-level.

Methodology

We combined qualitative and quantitative methods to examine change in students' three-dimensional learning of lunar phenomena after fieldtrip and classroom experiences, using interviews conducted before, immediately after, and one year later. Interviews were qualitatively coded and statistically analysed to examine change in concepts, patterns, and representations immediately after the intervention and one year later. The delayed post-interview allowed us to consider how these results compare to other studies showing the durability of student learning from fieldtrip experiences. Qualitative methods were used to examine affordances of instruction that may explain changes observed in student outcomes.

We previously published brief reports on this intervention for planetarium educators, discussing some of the conceptual gains from a sub-set of the data (Small & Plummer, 2014a, 2014b). This manuscript provides new analysis of broader set of the data, in order to focus on students' opportunities to engage in three-dimensional learning and the design of the learning environment.

Instructional context

The study took place in a suburban school district, in the North-eastern U.S., with a planetarium. The planetarium director (second author) taught planetarium instruction and classroom lessons, which took place in four 1st grade classrooms in one of the district's elementary schools (Table 1).

Planetarium program

We designed a planetarium program to engage children with three lunar phenomena: the Moon's surface features, the daily apparent daily motion of the Moon, and the lunar phases. Practices of science, appropriate to early elementary school and this domain, were embedded in the program including: scientific observation and creating representations. A character in the program made observations, recorded these in a science notebook, and generated representations using drawings and photographs. The planetarium director engaged the children in making their own observations and discussing how the character recorded his findings. The planetarium program used a *modular design* (Small & Plummer, 2010), which combines multiple, relatively short segments of pre-rendered digital visualizations on the planetarium dome interspersed with opportunities to engage

Table 1. Descriptions of the students' experience during the planetarium fieldtrip and classroom instruction.

	Location	Instruction
Day 1 (30–45 min)	Classroom	Students are introduced to the nature of the planetarium and the general topics of their visit. They make observations of the daytime sky and discuss differences between day and night.
Day 2 (55–60 min)	Planetarium fieldtrip	Children are engaged in a series of three related modules, moving between observing a pre-rendered visualization of the lunar phenomena on the dome and discussions with the planetarium director. The two visualizations included in this study showed: (1) a child watching the Sun and Moon appear to rise and set over the course of the day and night then drawing this in his science notebook and (2) a child observing the phases of the Moon change over the month then organizing a series of Moon cards to show their pattern.
Day 3 (28–35 min)	Classroom	Students work in small groups on a series of three activities that apply what they learned about the phenomena in the planetarium. The two activities analyzed for this study were: (1) children organize images of the full Moon in the night sky taking at different times of night to show how it appears to rise/set then develop a representation of this apparent motion; (2) children use a set of Moon phase cards to make predictions about what phase the Moon will be in on a future date.

the audience in live discussion. Collins and Greeno suggest, '[v]ideo and computer technology has enhanced the ability to create simulation environments where students are learning skills in context' (2011, p. 66). Thus, in consideration of the situative view of learning, the planetarium environment allowed the children to learn in an immersive environment designed to simulate observations in nature. Live discussions with the planetarium director, in combination with video segments, were designed to actively engage children using strategies that help them focus on key conceptual elements, such as checking predictions and mimicking patterns kinaesthetically (Plummer, 2009a). The length of the planetarium program was between 55 and 60 min for each class.

Classroom instruction

The fieldtrip to the planetarium took place between two classroom-based lessons. Students learn more on fieldtrips when they are oriented to the nature of the fieldtrip and expected experiences (DeWitt & Storksdieck, 2008; Griffin & Symington, 1997). Therefore, we designed the first classroom lesson as an opportunity for the children to begin thinking about the content of the program and to be oriented to what they would experience on the trip. The planetarium director engaged the children in a discussion of their ideas of what is visible in the day and night skies. Children then made observations of the daytime sky out their classroom window and viewed photographs of the night time sky; they discussed the differences they observed. The pre-fieldtrip lessons lasted between 30 and 45 min.

The post-fieldtrip lesson was designed to provide an opportunity for children to apply concepts they learned during the fieldtrip and engage in sense-making with their peers through opportunities for use of science practices (e.g. Anderson et al., 2000). Children engaged in activities that applied the main concepts from the planetarium program. Children worked in small groups to collaboratively develop a representation or make a prediction; this was followed by the planetarium director bringing the class together to share their conclusions (see Findings for further details). The post-fieldtrip lessons lasted between 28 and 35 min.

Participants and data collection

Each of the four first-grade classrooms had 18–20 students (6–7-year-olds); 11–12 students per classroom had parental consent to participate in the study ($N = 46$ across all four classrooms; 23 male, 23 female).

A random selection of students, alternating between male and female students, was interviewed approximately one week before and after instruction. Each student was interviewed about two of the three lunar phenomena from the planetarium program; in this manuscript, we describe findings associated with two phenomena: the apparent daily motion of the Moon ($n = 25$; 13 male, 12 female) and monthly cycle of lunar phases ($n = 26$; 12 male; 14 female). These two phenomena were chosen because they require an understanding of a repeated temporal pattern and thus engage children in a coherent *cross-cutting concept* for our focus on three-dimensional learning. We used a clinical interview protocol to encourage students to express their ideas verbally, as well as through gestures and drawings (Ginsburg, 1997). Interviews were video and audio recorded. Interview questions can be found online in supplemental Appendix A and throughout the findings section. Table 2 reviews the number of participants, topics of the interviews, and analyses performed.

Classroom lessons were video recorded for each of the four classrooms, with video cameras pointed at the whole class from the front of the classroom and the back of the classroom, and audio recorders placed with student groups. The planetarium programs were audio recorded, with three audio recorders spaced around the dome, for later analysis.

One year after the intervention, some students ($N = 16$) were re-interviewed using the same protocol, resulting in 11 students interviewed about the apparent daily motion of the Moon and 11 students interviewed about lunar phases.

Table 2. Interview data sources and analyses.

Phenomena	Interviews	Coding for concepts and patterns[a]	Coding for representations[a]	Statistical analysis
Apparent motion of the Moon	Year 1 ($n = 25$) Longitudinal ($n = 11$)	The daily apparent East-to-West rising and setting motion of the Moon	Use of lines, arrows, and/or multiple moons to represent motion for the apparent daily motion of the Moon	Rank-order codes according to concepts/ representational choices; Performed Wilcoxon-signed ranks test
Phases of the Moon	Year 1 ($n = 26$) Longitudinal ($n = 11$)	The monthly cycle of waxing and waning lunar phases	Organization of how lunar phases are drawn to represent the pattern of lunar phases	

[a]All codes can be found in Supplemental Appendix B.

Analysis

While our research focuses at the intersection of the three dimensions of learning, due to the complexity of this type of learning goal, we analysed their interview responses in ways that allowed us to shift the focus of our emphasis across different dimensions of the complete three-dimensional learning goal. From this, we can tease out aspects of their learning that might otherwise be hidden had we combined the three dimensions across the analysis.

Coding

A codebook was developed for each interview protocol to analyse students' understanding of lunar phenomena, beginning with prior research on children's conceptions about the Moon (e.g. Hobson et al., 2010; Plummer, 2009b) then refining codes through further interrogation of our data. The first set of codes highlights the children's understanding of concepts within the *disciplinary core idea* and the *understanding of patterns* of the two lunar phenomena: (1) the daily apparent East-to-West rising and setting motion of the Moon and (b) the monthly cycle of waxing and waning lunar phases. The second set of codes focused on choices students made when *representing* these phenomena: (1) use of lines, arrows, and/or multiple moons to represent motion for the apparent daily motion of the Moon and (2) organization of how lunar phases are drawn to represent the pattern of lunar phases. Each of these sets of codes can be found in the codebook, in supplemental Appendix B.

The first two authors independently coded the same subset of 20 interviews (32–33% of interviews from each protocol) across two rounds of coding comparison and then calculated Cohen's kappa coefficient for inter-rater reliability for each category. Based on the guidelines from Landis and Koch (1977), the kappa for nearly all categories suggests almost perfect agreement ($\kappa = .85–1$), and substantial agreement for the representation category of use of lines/arrows to represent motion ($\kappa = .78$).

Pre/post/delayed-post comparison of students' conceptions and representations of lunar phenomena

Codes were organized into a ranked order and assigned a numerical value, based conceptual sophistication. Using these numerical values, we performed a Wilcoxon signed-ranks test comparing pre/post responses to each category. We repeated our use of the Wilcoxon signed-ranks test to compare the delayed-post interview codes to the pre- and post-visit responses for the sub-set of students who were interviewed one year after the intervention.

Our analysis of students' representations included a statistical comparison following similar steps as described for the conceptual analysis, but focusing on codes describing choices they made when representing the phenomena. We identified productive elements common across multiple student representations—productive in terms of how they communicated the scientific concepts—and looked for change in how these elements were represented before and after instruction.

Analysis of instruction

We used the audio and video recordings of the instruction to analyse how their experiences during instruction may have influenced changes in their three-dimensional learning. Because we were interested in understanding the nature of their experience in these learning environments, we used thematic analysis (Braun & Clarke, 2006) to identify potential themes in the data set. Thematic analysis allows for both inductive and deductive coding and can be used to flexibly identify patterns in qualitative data sets and to provide potential interpretation when combined with an existing theoretical framework. Thus, we drew on the socio-constructivist theoretical framework in this analysis as it prompted us to attend to multiple levels of influence on children's experience, including social interactions, the virtual experiences in the planetarium and classroom, and physical artefacts (as seen in the video data) available in the classroom as we looked across the data.

Analysis of the classroom and planetarium audio/video data used an open-coding process. Coding the first classroom lesson and the planetarium lesson focused at the whole-group level. Open-coding of the second classroom lesson looked about both the whole-group level but also examined the nature of children's interactions in small group work by transcribing conversations from one or two small groups per classroom (~30% of consented children). The open-coding process was guided by the question: How did instruction support children's engagement in three-dimensional learning? Following the process outlined by Braun and Clarke (2006), we used this question to generate themes from the data. While open-coding, through an inductive process, led to the generation of initial themes, we then returned to findings from the interview to guide data analysis towards answering the question, What features of the learning environment related to changes observed in children's three-dimensional learning? These themes, and the evidence supporting them, were reviewed and discussed between both authors. From these themes, we developed potential explanations and relationships between students' experiences in the fieldtrip and classroom and their improved three-dimensional learning outcomes.

Findings: interview analyses

We present our findings on how children's conceptual knowledge and representational practice for patterns in lunar phenomena changed after a fieldtrip, including the relative durability of their three-dimensional learning based on interviews conducted one year later. As described in our coding process, we have framed our codes in ways that foreground different aspects of three-dimensional learning. One set of analyses foregrounds the students' understanding of the *disciplinary core idea* and application of *patterns* as they describe lunar phenomena. The other set of analyses, while also considering the students' conceptual understanding and patterns, foregrounds their choices in creating *representations*.

Apparent daily motion of the Moon

Concepts and patterns

We asked the children to imagine they were outside observing the Moon all night long: 'Do you think the Moon would look like it moves?' Children were given a paper showing a line indicating the ground, labeled East and West, and asked 'Can you draw me a picture of *how the Moon appears to move* (or, *what you told me the Moon does at night*)?' Students exhibited little difficulty in responding to the prompt, as their verbal descriptions were consistent with their use of the 2D drawing space. We interpreted students' understanding of the apparent motion of the Moon as an indication of their *conceptual* understanding, which includes a notion that the Moon exhibits a *repeating pattern* of motion. Students' verbal descriptions, as well as their drawings, were considered in the coding process.

Prior to the fieldtrip, nearly half did not believe the Moon appears to move (see Table 3). Children improved significantly in their descriptions of the Moon's apparent motion ($Z = 3.982$, $p < 0.0001$),

Table 3. Descriptions of the Moon's apparent motion, before and after the fieldtrip.

	No motion described	Moon appears to move	Moon rises/sets on opposite sides of sky	Moon rises East to West
Year 1 sample[a]				
Pre ($n = 25$)	12 (48%)	11 (44%)	0	2 (8%)
Post ($n = 25$)	1 (4%)	5 (20%)	1 (4%)	18 (17%)
Longitudinal sample[b]				
Pre ($n = 11$)	5 (45%)	5 (45%)	0	1 (9%)
Post ($n = 11$)	1 (9%)	0	1 (9%)	9 (82%)
Delayed post ($n = 11$)	1 (9%)	2 (18%)	2 (18%)	6 (55%)

[a,b]A portion of the data appears in Small and Plummer (2014a, 2014b).

moving towards a normative description of the Moon rising in the East and setting in the West. As an example of this type of change, Cynthia initially drew a series of moons showing different phases across the top of the sky but did not intend for these to show motion (see Table 5 for her drawings). She explained 'The clouds that are polluting. And you can't see the … ' The interviewer asks if that is why the Moon is changing shape. 'Yes. That's the cloud pollution.' The interviewer asked her if she would see all of the moons she drew in one night. She explained 'No … You're probably see this moon [points]. The next night you see this one, next, next, next, next, next and no moon [pointed at successive moons].' After instruction, she drew a series of full moons in an arc, rising and setting. Cynthia explained 'This is part of the month where it's full. Because it can't do all the phases in one night.' Asked how long it would take to see the moon go up and down like she drew, she responded 'All night.'

Representations

There was also progress in how students *represented* the Moon's apparent motion, shifting from many students not showing motion to nearly all students representing motion in their drawings. Before instruction, many students (32%) showed no motion in their representations. However, for those students who did represent motion, Table 4 shows the descriptive statistics for the two major representational features used by the students to indicate motion: drawing multiple moons across the page (52%) and using lines or arrows to show motion (25%). Table 5 shows five students' drawings and their progress. Before the fieldtrip, Brenda and Ryan used multiple moons to show motion while Cynthia used multiple moons to show change in the Moon over multiple days. Brenda and Ryan also use lines and arrows, respectively, to convey motion. After the fieldtrip, these five students all used multiple moons in their drawings to convey motion as well as showing the arc pattern of the Moon rising and setting.

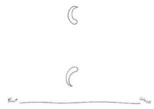
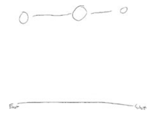
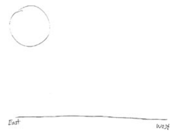
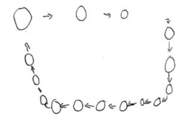
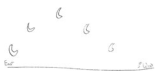
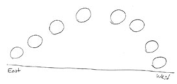
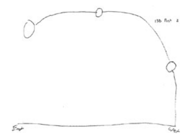
After the fieldtrip, the number of students who used multiple moons to communicate movement in their drawings increased significantly ($Z = -2.828$, $p < 0.01$), from 52% to 84%. The number of students who used lines or arrows increased slightly, from 28% to 36%, but was not significant. However, the *way* they used multiple moons and lines/arrows did change significantly after the fieldtrip.

Table 4. Representational analysis of the Moon's apparent motion, before and after the fieldtrip.

	Use of moons to indicate motion or path			Use of arrows and lines		
	One Moon	Multiple Moons	Other/ unclear	No extra marks	Lines/ dashes/ arrows	Other/ unclear
Year 1 sample						
Pre ($n = 25$)	11 (44%)	13 (52%)	1 (4%)	16 (64%)	7 (28%)	2 (8%)
Post ($n = 25$)	3 (12%)	21 (84%)	1 (4%)	14 (56%)	10 (40%)	1 (4%)
Longitudinal sample						
Delayed post ($n = 11$)	4 (36%)	7 (64%)	0 (0%)	5 (45%)	6 (55%)	0 (0%)

Note: Some students combined the use of multiple moons and lines/arrows to show motion.

Table 5. Examples of student representations of the Moon's apparent motion, before and after the fieldtrip.

	Laura (6 y.o.)	Brenda (6 y.o.)	Justine (7 y.o.)	Cynthia (7 y.o.)	Ryan (7 y.o.)
Pre					
Post					

Significantly more students showed the curved path of the Moon rising and setting using multiple moons (12% compared to 72%; $Z = -3.873$, $p < 0.001$) and/or arrows (0% compared to 36%; $Z = -3.000$, $p < 0.01$) after the fieldtrip.

Longitudinal results

Table 3 shows the results of delayed interviews, with a sample of students ($n = 11$), conducted one year after the original post-interviews. Results of a Wilson signed ranks test comparing pre- to post-interview results suggests that students in the longitudinal sample also improved in their descriptions of the Moon's apparent motion ($Z = -2.714$, $p < 0.01$). Many students retained the same level of knowledge of the Moon's apparent motion when comparing the post-interview to delayed-post ($Z = -1.063$, $p = 0.288$).

In terms of how they represented the apparent motion of the Moon, there was no significant difference between the students' use of multiple moons or arrows at post-fieldtrip and delayed interview. This suggests students were using similar representational strategies a year later.

Pattern of lunar phases

Concepts and patterns

After they drew their ideas about the lunar phase cycle (discussed further below), we gave the children eight photos showing each of the major phases of the Moon and asked them 'Can you put these in order of how we would see them in the sky?' After they placed the images in their selected order, we followed up by asking them what they would see after the last phase in their line of photos. This was used to engage them in talking about the next observations in the cycle so that we could determine their

Table 6. Cycle of lunar phases from photo-sort task, before and after the fieldtrip.

	Did not describe pattern as repeating	Waxes or wanes, phases not oriented consistently	Waxes or wanes then repeats	Repeating cycle or waxing and waning, but phases not all oriented consistently	Repeating cycle waxing and waning
Year 1 Sample[a]					
Pre ($n = 26$)	6 (23%)	10 (38%)	4 (15%)	2 (18%)	4 (15%)
Post ($n = 26$)	2 (18%)	6 (23%)	3 (12%)	6 (23%)	9 (35%)
Longitudinal Sample					
Pre ($n = 11$)	2 (18%)	3 (27%)	1 (9%)	2 (18%)	3 (27%)
Post ($n = 11$)	1 (9%)	2 (18%)	0	2 (18%)	6 (55%)
Delayed Post ($n = 11$)	5 (45%)	0	2 (18%)	0	3 (36%)

[a]A portion of the data appears in Small and Plummer (2014a).

understanding of the overall repeating *pattern* of lunar phases (see results in Table 6). As an example of this type of response, after organizing the photos showing new to full, Joshua points to the cards and says 'It starts going backwards' indicating that changing appearance reverses back to new.

Significant improvement was observed in their description of the cycle of the lunar phases ($Z = 2.931$, $p < 0.01$). Half of the students improved (50%), nearly half stayed at the same level of sophistication (46%), and one student regressed. Many children still did not show the cycle as both waxing and waning or did not orient the phases consistently (such as placing one crescent at a 90-degree angle to the orientation of the other crescent phase).

Students were asked about the length of the Moon's cycle of phases. A McNemar test (used with paired, nominal data) was used to compare students' knowledge of the length of the lunar cycle before and after the fieldtrip, a measure of their understanding of the temporal pattern of lunar phases. Students' knowledge that the Moon's cycle takes a month to complete improved significantly after the fieldtrip ($p < 0.01$). Prior to the fieldtrip, seven students (27%) said this was about a month; after the fieldtrip, this increased to 17 students (65%). Ten students improved and seven remained at the correct answer (no students regressed).

Representations

At the beginning of their interview, children were asked: 'Does the Moon ever appear in different shapes in the sky? Can you draw me a picture of those shapes?' We analysed the types of shapes they drew as well as how they organized those shapes, both from the perspective of the shift in conceptual understanding they expressed as well as their representational choices. The mean number of representations of phases drawn before the fieldtrip was 4.3 (SD = 2.1). The mean number of phases drawn after the fieldtrip was 7.3 (SD = 3.8). A paired sample *t*-test was used to compare the number of phases students drew before and after the fieldtrip. Students drew a significantly greater number of lunar phases after the fieldtrip than before ($t = -4.065$, $p < 0.0001$).

We examined whether their drawings of the lunar phases suggest they viewed the phase as a cycle or as a random collection of shapes (Table 7). The Wilcoxon signed ranks test was used to compare students' organization of the phases they drew from before to after the fieldtrip. Their drawings were significantly more normatively organized after the fieldtrip ($Z = -3.153$; $p < 0.01$). Though many children still drew random or alternative patterns (see codebook), after the fieldtrip more children organized the phases in ways that moved towards normative patterns of increasing or decreasing illumination.

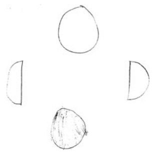
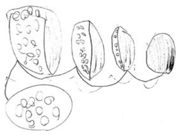
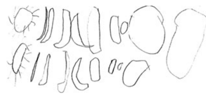
Table 8 shows examples of student drawings, before and after the fieldtrip, illustrating the different types of normative patterns, alternative patterns, and random organizations observed in children's drawings. As an example of a student who shifted towards a more sophisticated representation, in her pre-interview, Penny drew three images of the Moon. When asked if there are any other shapes the Moon could be in, she responded 'No.' In her post interview, she began by drawing half the cycle. She then stated, 'And then it goes the other way back' and drew the remaining phases.

Table 7. Change in children's representations of the lunar phases, before and after the fieldtrip.

	Random or alternative patterns	Increasing/decreasing but not all phases in half of a cycle	Half cycle	Full cycle
Year 1 sample				
Pre ($n = 26$)	20 (77%)	4 (15%)	2 (8%)	0
Post ($N = 26$)	14 (54%)	3 (12%)	5 (19%)	4 (15%)
Longitudinal Sample				
Pre ($n = 26$)	6 (55%)	3 (27%)	2 (18%)	0
Post ($n = 26$)	4 (36%)	1 (9%)	2 (18%)	4 (36%)
Delayed post ($n = 11$)	4 (45%)	0	6 (45%)	0

Note: A portion of the data presented in this table, from the longitudinal sample, originally appeared in Small and Plummer (2014b).

Table 8. Students' representations of the pattern of lunar phases, before and after the fieldtrip.

	Mark (7 y.o.)	Tim (6 y.o.)	Jon (6 y.o.)	Penny (7 y.o.)
Pre	 *Alternative pattern (incomplete)*	 *Random order*	 *Random order*	 *Increasing/ decreasing pattern*
Post	 *Half cycle*	 *Random order*	 *Increasing/ decreasing pattern*	 Full cycle

Longitudinal results

For the students in the longitudinal sample, we examined the results of both the photo-sort task and the drawing task. The Wilcoxon signed ranks test showed no significant difference between each of the three time points when considering the levels of sophistication of the lunar phase *pattern*, shown in Table 6.

We also used the Wilcoxon signed ranks test to compare students' *representations* of the lunar phases for the longitudinal student sample (Table 8). Students' organization in their drawings increased significantly from pre to post ($Z = -2.271$, $p < 0.05$). The comparison of the pre-drawings to delayed-post as well as post-drawings to delayed was not significant. However, many students were coded as regressing from post-visit to delayed-post. Most of this can be attributed to students who were coded as drawing a full cycle at post but drew half-cycles a year later. Thus, perhaps some of their improvement was maintained through their improved representation of the pattern even if it did not capture the full cycle.

Findings: affordances of classroom and fieldtrip instruction

We now discuss our interpretation of the interview results in light of the qualitative findings from the analysis of the intervention, as guided by our theoretical framework and the literature on classroom-fieldtrip interactions. We will discuss findings that emerged from our analysis, below: (1) The planetarium visit may have contributed to the changes in students' conceptual knowledge and recognition of temporal patterns. (2) Students' initial understanding through the fieldtrip experience was shaped by opportunities for sense-making with peers in the post-fieldtrip classroom lesson. (3) The students' development of representations appeared to be influenced by their initial ideas about how to represent the phenomena, with further mediation by the concepts learned in the planetarium and the interactions with their peers and artefacts during the post-visit lesson.

Apparent motion of the Moon

In the planetarium, students learned to describe the Moon's apparent daily motion using gestures to mimic the Moon's motion as they observed the simulation. They observed the program's cartoon child draw his own representation of the Moon's motion in his science

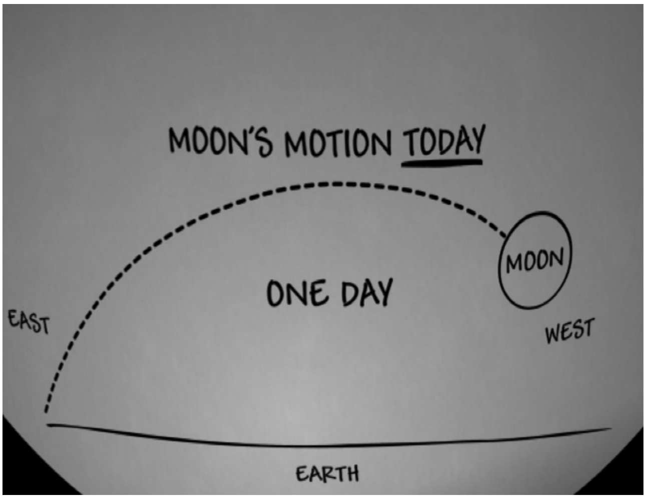


Figure 1. Representation of the Moon's apparent motion during planetarium program.

notebook (see Figure 1); the planetarium director discussed how the child used a notebook to track and represent the motion after this module. These experiences supported the students' development of conceptual knowledge of the Moon's apparent motion as well as how this is can be understood as a pattern of motion; students learned to describe how the Moon appears to rise and set in a smooth path through multimodal (visual, auditory, and kinaesthetic) observation-based experiences.

During the classroom lesson, the students were given sets of six images showing the full Moon, above a landscape to indicate its altitude above the horizon, at different times throughout the night. Students, in groups of two or three, put the images in order to show how the Moon appears to move throughout the night. Students often began by discussing the cardinal directions, labeled on the bottom of the images, as a way to help them organize the images. Many children focused on determining which image showed the Moon closest to the East to indicate the first image—a concept they learned in the planetarium program. Some groups also considered the altitude of the Moon in the sky as an additional indicator of the correct order. After organizing the images, each student drew their own representation of how the Moon appears to move across the sky, often working as a group by consulting each other's drawings. To conclude the activity, volunteers were called up to the front of the classroom to recreate their representation on a large paper, allowing the entire class to compare the public representation to their personal representation of the Moon's apparent motion. These publically reproduced and discussed representations used the multiple moons with dashed lines conventions to indicate the path across the sky; some also included arrows.

The students' post-interview representations did not often use the same representational choices as the one created by the cartoon child in the planetarium program (e.g. Figure 1). Instead, the students' favored drawing multiple moons across the sky; students who showed motion before the program used this strategy and many more children used this in their representations after the program. The repeated Moon feature and use of dashed lines or arrows all appeared to be strategies children used to show motion. Further, these representational strategies may have been influenced through the students' interaction with each other and the physical medium of the post-planetarium activity in three ways: (1) the activity involved organized multiple images of the Moon in the sky, (2) the students worked in small groups and thus saw how their peers represented the motion, and (3) public representation at the front of the classroom used the multiple moons with dashed lines connecting strategy.

Lunar phases

Prior to watching the lunar phases module, the students practiced identifying and naming the phases by observing images in the planetarium. During the module, students were prompted repeatedly to think about the *pattern* of the phases of the Moon as they observed the cartoon boy use his observations of the phases to reorganize his original representation into that pattern. Observing the boy create a representation of the lunar cycle in his science notebook reinforced the importance of noticing this increasing then decreasing appearance of lunar phases. The narrator discusses the observations as a repeating pattern; subsequently, the boy (and the audience) watch another month's worth of phases in the sky. This instruction may have supported students' conceptual understanding of the nature of the Moon's changing appearance as well as their understanding of the pattern of its repeating cycle. After the module concluded, the planetarium director engaged the students in thinking about the difference between the two phenomena they observed: the Moon's change in location during a single day and the pattern of change to its appearance over an entire month. Thus, the planetarium program encouraged students to think about the phases as an organized and repeating pattern, focusing both on the change in appearance and the timescale. This took place in the immersive environment of the planetarium, an environment which has previously been found to result in improved learning outcomes over classroom comparison groups for spatially-rich content areas with older populations (Yu, Sahami, Sahami, & Sessions, 2015).

During post-visit classroom instruction, most of the instructional focus was on making predictions about the day-by-day changes with less focus on full monthly pattern of lunar phase changes. Small groups of children were provided with a set of eight lunar phase photos and asked to make predictions about the Moon's appearance on their teacher's birthday, after being shown the Moon's phase a few days before her birthday. Students made observations of phases leading up to their teacher's birthday, made predications, and then made comparisons between the changes in the lunar phases, such as 'It got skinnier' or 'It is a little smaller.'

Classroom instruction also emphasized attending to the Moon's orientation as the phases changed. The planetarium director helped students notice which side of the Moon is illuminated when making their predictions, such as saying: 'Make sure to match the side,' and 'Which side of the Moon is lit up, the right or the left?' These experiences may have helped students attend to the importance of keeping the phases aligned when organizing them in a pattern. Overall, the post-visit classroom instruction may have helped students attend to which side of the Moon is illuminated and apply what they learned in the planetarium about subtle changes between lunar phases on successive days; this was mediated by the physical (Moon phase cards) and virtual (projected images of the Moon on different dates) environment available to them through social engagement in small group and whole group conversations with the planetarium director.

Discussion

Our findings demonstrate how these first-grade students developed more sophisticated three-dimensional learning (NRC, 2012) through an intersection of lunar phenomena concepts, lunar phenomena patterns, and representational practices as they participated in a planetarium fieldtrip experience and classroom instruction. Post-interviews demonstrated how the sophistication of children's drawn representations increased as they showed the patterns of both lunar phases and how the Moon appears to rise and set. Our study is one of only a few that demonstrate how young children can be engaged in the reform-based notion of three-dimensional learning, and does so from the unique perspective of how a fieldtrip can contribute to this type of learning for young children. During instruction, students observed the scientific phenomena using second-hand experience with the simulation in the planetarium. Students then used these observations, along with photographs provided in the classroom, as evidence to collaboratively develop and refine their own representations of the phenomena. Representing their conceptual understanding of these phenomena engaged the students with the foundations of celestial motion, a core disciplinary idea of astronomy, and the cross-cutting concept of patterns. Interviews with a subset of the students also suggests that they maintained all or some of their improved three-dimensional learning for at least a year after the fieldtrip. Thus, we add to the small, but valuable, literature on the long-term contribution of fieldtrips as informal venues for science learning (Bamberger & Tal, 2008).

By comparing students' improvement in understanding and representation to their opportunities to learn across the fieldtrip and classroom, we can provide suggestions on how these experiences worked together to shape their three-dimensional learning. First, the planetarium served as a resource for their conceptual learning and understanding of patterns of these lunar phenomena. Students made critical scientific observations in the planetarium to aid their understanding and develop new mental schemas. To support students' noticing, the planetarium director engaged students through verbal and visual cues, and in the case of the Moon's apparent motion, kinaesthetic-based experiences of tracing the shape of the Moon's path. These multimodal experiences supported the development of mental imagery of this concept; prior planetarium-based research suggests that having children physically trace the paths of celestial objects supports their development of embodied schemas of these conceptions (Plummer, 2009a; Plummer et al., 2014).

But their experiences in the socially interactive environment of the classroom may have also played a role in shaping their choices how they used the observational evidence from the planetarium in the representations (Brown et al., 1989; Collins & Greeno, 2011; Nersessian, 2004). The classroom activities emphasized and reinforced their understanding of aspects of the patterns in the phenomena. In other cases, children used their own choices in developing representations, in ways that suggest they were drawing on their observations during the fieldtrip and classroom lessons, to communicate new understanding of the concepts and patterns.

The progress observed in the students' three-dimensional learning of these lunar phenomena suggests they are well-positioned for future astronomy learning. These concepts and patterns are identified as important stepping-stones to build on for learning celestial motion as children progress in school (NRC, 2012; Plummer, 2012). Further, engaging children in developing scientific representations, using observations as evidence, is the first step towards more complex experiences in the science practices in later years (Danish & Phelps, 2011). Children's early representations in science are their opportunities to consider which elements of the observed phenomena are relevant to represent in order to communicate a concept or pattern. This process of selecting the relevant features of the phenomenon to represent moves children towards more sophisticated modeling practices, such as using representations as evidence to support a claim or make predictions (Lehrer & Schauble, 2012; Prain & Tytler, 2012).

However, while there was significant improvement for both phenomena, we also found that certain aspects of the combined fieldtrip and classroom experience were less successful in supporting their learning. Representing the full cycle of lunar phases continued to be a challenge for students after instruction; thus, the combination of planetarium and classroom, though sufficient to help children improve their conceptual understanding of the lunar phases pattern and ability to represent that pattern, was only an initial step towards the larger concept for many of these children. While the planetarium showed the entire cycle and how the cycle repeats, the classroom instruction was not design to engage students with that concept and pattern to include in their three-dimensional learning. Recognizing those areas children need support and carefully aligning both fieldtrip and classroom experiences to support those challenges may improve student learning in the future.

Prior research on first- and second-grade students learning about lunar phases found greater learning gains, compared to ours, when considering their conceptual understanding of the full cycle. Children spent five weeks observing lunar phases using a computer simulation before discussing their data to look for patterns, determining the length of the cycle, applying the scientific terminology for the phases of the Moon, and engaging in psychomotor modeling across multiple lessons (Hobson et al., 2010). However, our findings indicate that short interventions that combine a fieldtrip and classroom lesson have the potential to improve students' three-dimensional learning of lunar phases. Future research should focus on improving the connections across fieldtrip and classroom interventions for the potential for increased three-dimensional learning.

Implications for fieldtrips

Our study helps provide evidence that improvement in three-dimensional learning, such as demonstrated here through the fusion of lunar phenomena concepts, patterns, and representational practices, is within reach of classroom-fieldtrip learning opportunities. One model for supporting students in three-dimensional learning could follow steps similar to those outlined in this study. The fieldtrip can be an opportunity for helping students improve their observations of scientific phenomena by looking for patterns in those phenomena, as well as providing time for students to work together socially to make sense of their observations. In this study, the planetarium was used to present astronomical phenomena in ways that may be difficult to do in the classroom. The fieldtrip, therefore, can serve as the opportunity to make critical observations of scientific phenomena that may not be easily accessible in the classroom.

Those observations of science phenomena from the fieldtrip can support evidence-based science practices as part of three-dimensional learning. For three-dimensional learning to be successful, we suggest that children will need an opportunity to take the data they have gathered on their fieldtrip (e.g. their observations) and apply these in sense-making activities in the classroom. In this study, the post-visit classroom lesson provided the children with opportunities to discuss with their peers and apply what they observed of the lunar phenomena on the fieldtrip in ways that strengthened their understanding and may have allowed them to begin to consider those features of the lunar phenomena they attended to when developing representations (DeWitt & Storksdieck, 2008). The observations from the planetarium visit, along with other classroom resources (e.g. photographs), were used as evidence to support the development of representations of patterns to begin to make sense of the phenomena.

Thus, in our study, children combined the elements of three-dimensional learning in the post-visit lesson (concepts of lunar phenomena, patterns of change over time, and use of evidence to develop representations) by building on the concepts, patterns, and observations gathered during their fieldtrip. Future fieldtrips could support three-dimensional learning in other ways, by focusing on different cross-cutting concepts and science practices. However, building on the strengths of the fieldtrip to observe phenomena that are unique or difficult to replicate in the classroom and using their observations to support sense-making practices, such as modeling, argumentation, and constructing explanations, may provide the richest opportunities for learning in science.

Limitations and future research

Our goal was to investigate the potential for three-dimensional learning during a combination of planetarium fieldtrip and classroom lessons. We hoped to study what is possible, though not necessarily what is typical; thus, the planetarium director taught both the planetarium and classroom lessons. The extent to which teachers engage their students in lessons directly connect to fieldtrip experiences is often limited (Griffin & Symington, 1997; Kisiel, 2005); therefore, this kind of short, yet purposefully designed, classroom-fieldtrip integration might help teachers and informal educators work together towards making three-dimensional learning a goal for elementary students. Future research may consider the extent to which results such as those shown here can be replicated when informal educators and classroom teachers work together around three-dimensional learning on fieldtrips.

We are limited in that we cannot unequivocally distinguish between what students learned on the fieldtrip and in the classroom, as we did not have comparison groups who received only planetarium or classroom lessons. However, because prior studies provide evidence that suggests combining a fieldtrip with classroom curriculum improves learning (e.g. Anderson et al., 2000; Lucas, 2000), we purposefully chose this model of education as the most ethical for the students involved in the study.

A further limitation of this study was that the children developed the representations we assessed during interviews rather than the classroom (though they did develop other representations together in the classroom); however, teachers could use a similar prompt to create representations as part of their pre- and post-visit classroom lesson. Doing so would allow children the opportunity engage with their initial conceptions of a phenomenon, which would help them prepare for what they would be learning about on their fieldtrip, and then later to revisit their ideas and revise their initial representation, after the fieldtrip. Further, future research may explore the potential for fieldtrips to engage students through computer-aided learning, including mobile devices, that could facilitate their engagement in recording observations, generating representations, and making sense of phenomena in ways that allow them to carry ideas, information, and data from one setting to the next, to support further learning.

Acknowledgements

We would like to thank Joanne Young and Audio Visual Imagineering for supporting and funding the production of the planetarium program as well as the teachers who worked with us to implement the instruction with their students.

Disclosure statement

In accordance with Taylor & Francis policy and our ethical obligations as researchers, we are reporting that the second author receives royalties from sales of the planetarium program produced as a result of this study.

Funding

This work was partially funded by a Middle Atlantic Planetarium Society (MAPS) Education Research Grant.

ORCID

Julia D. Plummer http://orcid.org/0000-0003-4144-7864

References

Anderson, D., & Lucas, K. B. (1997). The effectiveness of orienting students to the physical features of a science museum prior to visitation. *Research in Science Education*, *27*(4), 485–495.

Anderson, D., Lucas, K. B., & Ginns, I. S. (2003). Theoretical perspectives on learning in an informal setting. *Journal of Research in Science Teaching*, *40*(2), 177–199.

Anderson, D., Lucas, K. B., Ginns, I. S., & Dierking, L. D. (2000). Development of knowledge about electricity and magnetism during a visit to a science museum and related post-visit activities. *Science Education*, *84*(5), 658–679.

Bamberger, Y., & Tal, T. (2008). An experience for the lifelong journey: The long-term effect of a class visit to a science center. *Visitor Studies*, *11*(2), 198–212.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77–101.

Brazell, B. D., & Espinoza, S. (2009). Meta-analysis of planetarium efficacy research. *Astronomy Education Review*, *8*(1). doi:10.3847/AER2009033.

Brooks, M. (2009). Drawing, visualisation and young children's exploration of "big ideas". *International Journal of Science Education*, *31*(3), 319–341.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Collins, A., & Greeno, J. G. (2011). Situative view of learning. In V. G. Aukrust (Ed.), *Learning and cognition in education* (pp. 64–68). Amsterdam: Elsevier.

Cox-Petersen, A. M., Marsh, D. D., Kisiel, J., & Melber, L. M. (2003). Investigation of guided school tours, student learning, and science reform recommendations at a museum of natural history. *Journal of Research in Science Teaching*, *40*(2), 200–218.

Danish, J. A., & Phelps, D. (2011). Representational practices by the numbers: How kindergarten and first-grade students create, evaluate, and modify their science representations. *International Journal of Science Education*, *33*(15), 2069–2094.

DeWitt, J., & Osborne, J. (2010). Recollections of exhibits: Stimulated-recall interviews with primary school children about science centre visits. *International Journal of Science Education*, *32*(10), 1365–1388.

DeWitt, J., & Storksdieck, M. (2008). A short review of school field trips: Key findings from the past and implications for the future. *Visitor Studies*, *11*, 181–197.

diSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction*, *22*(3), 293–331.

Ginsburg, H. (1997). *Entering the child's mind: The clinical interview in psychological research and practice*. New York: Cambridge University Press.

Griffin, J., & Symington, D. (1997). Moving from task-oriented to learning-oriented strategies on school excursions to museums. *Science Education*, *81*(6), 763–779.

Gutwill, J. P., & Allen, S. (2012). Deepening students' scientific inquiry skills during a science museum field trip. *Journal of the Learning Sciences*, *21*(1), 130–181.

Hein, G. E. (1998). *Learning in the museum*. New York: Routledge.

Hobson, S. M., Trundle, K. C., & Saçkes, M. (2010). Using a planetarium software program to promote conceptual change with young children. *Journal of Science Education and Technology*, *19*(2), 165–176.

Kallery, M. (2011). Astronomical concepts and events awareness for young children. *International Journal of Science Education*, *33*(3), 341–369.

Kisiel, J. (2005). Understanding elementary teacher motivations for science fieldtrips. *Science Education*, *89*(6), 936–955.

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the next generation science standards. *Journal of Science Teacher Education*, *25*(2), 157–175.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*, 159–174.

Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education*, *96*(4), 701–724.

Lucas, K. B. (2000). One teacher's agenda for a class visit to an interactive science center. *Science Education*, *84*(4), 524–544.

Metz, K. E. (2004). Children's understanding of scientific inquiry: Their conceptualization of uncertainty in investigations of their own design. *Cognition and Instruction*, *22*(2), 219–290.

Miglietta, A. M., Belmonte, G., & Boero, F. (2008). A summative evaluation of science learning: A case study of the Marine Biology Museum "Pietro Parenzan" (South East Italy). *Visitor Studies*, *11*(2), 213–219.

National Research Council. (2009). *Learning science in informal environments*. Washington, DC: National Academy Press.

National Research Council. (2012). *A framework for K-12 science education*. Washington, DC: National Academy Press.

National Research Council. (2014). *Developing assessments for the next generation science standards.* Washington, DC: National Academies Press.

Nersessian, N. J. (2004). Interpreting scientific and engineering practices: Integrating the cognitive, social, and cultural dimensions. In *Scientific and Technological Thinking* (pp. 17–56). Mahwah, NJ: Earlbaum.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Papandreou, M. (2014). Communicating and thinking through drawing activity in early childhood. *Journal of Research in Childhood Education*, *28*(1), 85–100.

Plummer, J. D. (2009a). A cross-age study of children's knowledge of apparent celestial motion. *International Journal of Science Education*, *31*(12), 1571–1605.

Plummer, J. D. (2009b). Early elementary students' development of astronomy concepts in the planetarium. *Journal of Research in Science Teaching*, *46*(2), 192–209.

Plummer, J. D. (2012). Challenges in developing and validating an astronomy learning progression. In A. Alonzo & A. W. Gotwals (Eds.), *Learning progressions in science: Current challenges and future directions* (pp. 77–100). Rotterdam, The Netherlands: Sense Publishers.

Plummer, J. D., Kocareli, A., & Slagle, C. (2014). Learning to explain astronomy across moving frames of reference: Exploring the role of classroom and planetarium-based instructional contexts. *International Journal of Science Education*, *36*(7), 1083–1106.

Prain, V., & Tytler, R. (2012). Learning through constructing representations in science: A framework of representational construction affordances. *International Journal of Science Education*, *34*(17), 2751–2773.

Rennie, L. J., & McClafferty, T. P. (1996). Science centres and science learning. *Studies in Science Education*, *27*, 53–98.

Roth, W. M., & McGinn, M. K. (1998). Inscriptions: Toward a theory of representing as social practice. *Review of Educational Research*, *68*(1), 35–59.

Schmoll, S. E. (2013). *Toward a Framework for Integrating Planetarium and Classroom Learning* (Doctoral dissertation, University of Michigan).
Schwartz, D. L., & Heiser, J. (2006). Spatial representations and imagery in learning. In *The Cambridge handbook of the learning sciences* (pp. 283–298). New York: Cambridge University Press.
Siry, C., Ziegler, G., & Max, C. (2012). "Doing science" through discourse-in-interaction: Young children's science investigations at the early childhood level. *Science Education*, *96*(2), 311–326.
Small, K., & Plummer, J. D. (2014a, Summer). Impact on children's conceptual constructs regarding observational features of the moon: A look at elements of program and instruction design for early elementary-aged students. The Constellation, No. 2, 2–4, 7.
Small, K., & Plummer, J. D. (2014b). A longitudinal study of early elementary students' understanding of lunar phenomena after planetarium and classroom instruction. *The Planetarian*, *43*(4), 18–21.
Small, K. J., & Plummer, J. D. (2010). Survey of the goals and beliefs of planetarium professionals regarding program design. *Astronomy Education Review*, *9*(1), 010112-1–010112-10.
Storksdieck, M. (2006). *Field trips in environmental education*. Berlin, Germany: Berliner Wissenschafts-Verlag.
Varelas, M., Pappas, C. C., Kane, J. M., Arsenault, A., Hankes, J., & Cowan, B. M. (2008). Urban primary-grade children think and talk science: Curricular and instructional practices that nurture participation and argumentation. *Science Education*, *92*(1), 65–95.
Vygotsky, L. (1978). Interaction between learning and development. *Readings on the Development of Children*, *23*(3), 34–41.
Yu, K. C., Sahami, K., Sahami, V., & Sessions, L. (2015). Using a digital planetarium for teaching seasons to undergraduates. *Journal of Astronomy & Earth Sciences Education (JAESE)*, *2*(1), 33–50.