J Sci Teacher Educ
DOI 10.1007/s10972-010-9189-9

Inquiry and Astronomy: Preservice Teachers' Investigations of Celestial Motion

Julia D. Plummer · Valerie M. Zahm · Rebecca Rice

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Abstract This study investigated the impact of an open inquiry experience on elementary science methods students' understanding of celestial motion as well as the methods developed by students to answer their own research questions. Pre/post interviews and assessments were used to measure change in participants' understanding ($N = 18$). A qualitative approach was used to describe the nature of each participant's investigation through an analysis of their science journal and poster presentations. A comparison of participants' inquiry projects with the change in their understanding revealed that while most participants improved in both their area of inquiry and beyond, elementary science methods students may need more guidance to reach a full scientific understanding across all aspects of celestial motion.

Keywords Inquiry · Elementary teachers · Astronomy · Science methods course

Introduction

Standards documents published at the national level (National Research Council [NRC] 1996; American Association for the Advancement of Science [AAAS] 1993) and the state level (Palen and Proctor 2006) recommend that elementary school

J. D. Plummer (✉)
Department of Education, Arcadia University, 450 S. Easton Road, Glenside, PA 19038, USA
e-mail: plummerj@arcadia.edu

V. M. Zahm
Millersville University, University Campus, Millersville, PA 17551, USA

R. Rice
Easton Middle School, 201 Peachblossom Road, Easton, MD 21601, USA

children learn how to explain the apparent patterns of motion of the sun, moon, and stars using the actual motion of the earth and moon. Yet research indicates that both children and teachers often hold alternative conceptions in this domain (Baxter 1989; Mant and Summers 1993; Plummer 2009a; Trumper 2001a, 2003). Elementary teachers have limited time to learn all of the science that they will need during their careers. Therefore, our goal was to investigate how much preservice teachers can learn through their own inquiry during a science methods course with minimal structure provided. While we may not expect teachers to undertake this kind of in-depth investigation on their own, the results of this study improves our knowledge of preservice elementary teachers' ability create their own celestial motion investigations and the resulting improvement in their understanding.

For teachers to be prepared to help elementary students develop these concepts, they will need a deep and rich understanding of celestial motion as well as strategies they can use to teach these concepts. Celestial motion includes both what we can see from an earth-based perspective (apparent motions) and the explanations for those motions. Apparent celestial motion includes the sun's rising and setting motion across the seasons, the moon's rising and setting motion, and the stars' apparent motion throughout the night. The explanation for all of these involves the slow rotation of the earth on a daily basis. The ability to explain observable phenomena (e.g., the apparent motion of the sun, moon, and stars, seasons, and phases of the moon) using the actual motion of celestial objects is a fundamental aspect of astronomy knowledge.

Elementary Teachers' Alternative Ideas About Astronomy

Surveys with large numbers of preservice and practicing teachers suggest that most do not hold the scientific conception for many sun-earth-moon concepts (Brunsell and Marcks 2005; Schoon 1995; Trumper 2001b, 2003, 2006). Mant and Summers (1993) concluded that the English elementary teachers in their interview study did not have a good observational foundation and were instead working from non-scientific "mental models" to formulate inaccurate descriptions of the apparent motion of the sun, moon, and stars. A large fraction of both American and English teachers and preservice teachers hold alternative ideas about the explanation for why we have day and night, such as the sun moving around the earth (Atwood and Atwood 1995; Mant and Summers 1993; Parker and Heywood 1998). Many American preservice teachers also hold alternative ideas about the phases of the moon (Trundle et al. 2002, 2006) and the explanation for the seasons (Atwood and Atwood 1995).

Instruction Designed to Improve Teachers' Understanding of Astronomy

Improving the quality of astronomy education goes beyond identifying the problem areas; science education researchers need to put more effort into analyzing instruction designed to improve understanding (Bailey and Slater 2003). The use of models has been found to be a successful strategy in teaching the day/night cycle

(Atwood and Atwood 1995), phases of the moon (Callison and Wright 1993; Trundle et al. 2002), and the seasons (Atwood and Atwood 1995). The instruction in Trundle et al.'s studies (2002, 2006, 2007), which included extended observations and sharing within groups, improved the students' ability to describe the changing appearance of the moon. Studies have also examined preservice teachers learning about the phases of the moon through online interactions with peers in another country (Mulholland and Ginns 2008; Wilhelm et al. 2007). The online discussion format provided preservice teachers an opportunity to construct and display their developing understanding of lunar concepts in a public forum. Trumper (2006) found that preservice teachers who participated in a series of highly guided investigations of the sun's path, daily temperatures, and sunrise/sunset times as well as in-class modeling exercises showed higher gains than college students in traditional instruction.

Context of the Study

A common theme across successful preservice teacher astronomy education interventions is the time and effort taken to support guided inquiry investigations. Opportunities for extended investigations are limited and require the guidance of a knowledgeable facilitator. In their future teaching careers, teachers may find themselves responsible for many different aspects of astronomy, depending on the age of the students and the school's science standards. Thus, teachers need to be prepared to be creative and flexible on the investigations they are able to enact to meet their learning goals for future students. Yet teachers lack content knowledge and have limited time in their preservice course work in which to learn both astronomy and inquiry skills. Our study approaches these problems by assessing the learning outcomes of preservice teachers who design and implement their own inquiry investigations, with limited constraints to their approach or guidance in analyzing their data for patterns and explanations.

The primary purpose for including this extended investigation of celestial objects in the elementary science methods course was to give these students an experience of scientific inquiry as described in *Inquiry and the National Science Education Standards* ([*INSES*]; NRC 2000). Many preservice and practicing elementary teachers have a limited understanding of the nature of science and a poorly developed understanding of how to teach science with an inquiry approach (Abd-El Khalick and Lederman 2000; Akerson et al. 2007; Bransford et al. 1999; Donovan and Bransford 2005; Duschl et al. 2007; Eick and Reed 2007; Lederman 1992). Research suggests that involving preservice teachers in their own inquiry investigations will improve their understanding of the process of science, help them develop an understanding of what it means to be a scientist, increase their confidence in their abilities in science, and influence their likelihood of including inquiry as part of their own science teaching (Haefner and Zembal-Saul 2004; Melear et al. 2000; Morrison 2008; Shapiro 1996; Windschitl 2003). With inquiry as an integral part of the framework of the course, we chose to aim our research focus on uncovering the ways that this experience would improve preservice teachers understanding of the astronomy concepts which they investigated. Due to time constraints and potential bias by the researcher, the preservice teachers' understanding of inquiry was not investigated.

Rather than narrowly focusing on one aspect of observational astronomy, we investigated whether or not opening the inquiry to a larger area of potential questions would result in improved understanding across the domain. We used open inquiry in which the student has responsibility for asking their own scientific question and designing an appropriate investigation (Windschitl 2003). We have also examined the tools, resources, and ideas that preservice teachers used to develop their own inquiry investigations to understand their resourcefulness in pursuit of a scientific question. The following research questions guided this study:

1. What celestial motion topics and investigative approaches did the elementary science methods students choose in an open-inquiry environment?
2. In what ways did the elementary science methods students' knowledge change as a result of their own inquiry investigations and in-class activities?

Methodology

Participants

This study involved students ($N = 18$; 16 women and 2 men) in an elementary science methods course at a small comprehensive university. An additional student chose not to participate in the research but completed the instructional aspects as part of the course. Most of the participants were working towards elementary and/or special education certification; three were current teachers (pre-kindergarten, sixth grade, and middle school math). Two participants were undergraduate elementary education majors and the remaining were graduate students (most were working towards elementary-level certification). Four participants had one or more previous astronomy courses. The lead author of this study was also the professor. The coauthors were research assistants and not involved with instruction.

Instruction

The 9-week astronomy inquiry project took place from January through March with estimated 49–55% monthly clear skies (HAMweather 2009). While most participants based their projects on observations from the university's location, two participants added additional observations from other locations (one several degrees north and the other several degrees south). About 30–60 min were spent in class every other week for a total of about 200 min of in-class time. Participants spent most of this time in groups discussing, analyzing, and attempting to explain their observations or presenting their observations to class. Participants recorded their questions, plans, observations, and explanations in a science journal.

Week 1

Following the pre-assessment, participants were encouraged to suggest ways they could begin to test their pre-assessment responses. The professor led a discussion about the observations they might choose to make over the next 2 weeks and what they predicted they would observe. The features of inquiry were discussed, as described by *INSES*: (a) respond to scientific questions, (b) base explanations on evidence of the natural world, (c) analyze explanations in light of alternative explanations, and (d) communicate the proposed explanations in ways that allow others to replicate their procedures. The class discussion focused on key concepts included within inquiry, specific examples of evidence, and the use of explanations. Participants worked in small groups to discuss examples of science investigations conducted by elementary children.

Week 3

Participants worked in groups to discuss their observations of the previous 2 weeks and narrow their inquiry question to one aspect of observable celestial motion. Participants chose groups based on the concept areas (sun, moon, or stars) on which they had observed over the previous weeks. Participants were asked to compare their observations, decide if they could support their predictions, and propose new questions.

Week 5

Participants worked in their groups to create a poster and present their observations to the class. They were asked to create a display of the data collected and to look for patterns in their data. Participants then planned their next observations, predicted what they would observe, and wrote about how this would answer their questions.

Week 7

Participants were instructed to use physical models of the sun, earth, and moon to try to explain their observations after watching the instructor model and explain why we see different stars over the course of the year. Participants were given a brief lecture on some basic concepts (e.g., earth's rotation, moon's orbit). Participants were provided written explanations of celestial motion from an online source for educators (Lunar and Planetary Institute 2007).

Week 9

Participants presented posters describing their group's projects. Each group was asked to find a way to combine their projects to answers to the following questions: What question(s) are you trying to answer or observations are you trying to explain? What data did you collect? What is your claim or conclusion? How can you explain your observations?

Data Collection and Analysis

Multiple forms of data informed our analysis in order to triangulate our interpretation of the data (Borg and Gall 1989). First, all participants took pre- and post-instruction written surveys on celestial motion. Second, all participants were invited to be interviewed; however, only eight were available for both pre- and post-instruction interviews (conducted the week following the pre- and post-assessments). Interviews, covering the same concepts as the surveys, were designed to provide case studies of individual participant's progress through the investigation but were primarily used in this manuscript to triangulate on our other data collection methods. Third, we copied each participant's science notebook and presentation posters.

To simplify the analysis, a flowchart was created for each of the participant's science journals to graphically organize the entries. Figure 1 shows the flowchart created from Amie's journal (all names are pseudonyms). Amie's flowchart was chosen for this manuscript because the low number of entries allowed it to be condensed (original flowcharts were 11″ × 17″). Each journal was coded to find all entries that fit one of the categories: question, hypothesis, procedure, data, analysis, and conclusion. Some entries (such as research questions or succinct descriptions) were entered verbatim (in quotes) to the flow charts. Longer entries and data collected over time were summarized. A similar process was used for both of the posters created by each group, and information was integrated into the flow charts. Finally, links were made between categories to indicate the flow from initial question to conclusion (though not every entry could be linked to a specific line of research and some lines ended prior to the analysis or conclusion stage as participants' focus narrowed). The flowcharts tracked the progression of the participant's investigation and allowed us to make connections between journal and poster text with the participant's change in understanding measured by the pre/post assessment.

A document analysis approach was used to answer the first research question (Borg and Gall 1989; Wiseman 1999). Participants' flowcharts were examined to identify the conceptual areas in which they chose to work. We also classified the nature of the investigations, initially based on a set of predefined codes describing aspects of their investigative approaches. Through an iterative, open-coding approach we added additional codes describing the participants' approaches to investigating (Strauss and Corbin 1998). Through this we identified general themes in the types of investigations and methods participants' chose to pursue. A similar approach was taken to identify challenges and solutions which participants faced in the course of their investigative process.

A pre-experimental, one-group pretest–posttest design was used to answer the second research question (Campbell and Stanley 1963). Survey questions and interview questions were based on unpacking the domain (Shin et al. in press) and previous research in this area (Mant and Summers 1993; Plummer 2009a). During the written assessment, participants drew their description of the sun, moon, and stars' apparent motion, from an earth-based perspective, on a small clear plastic hemisphere and wrote explanations for these patterns (Appendix 1). The interview

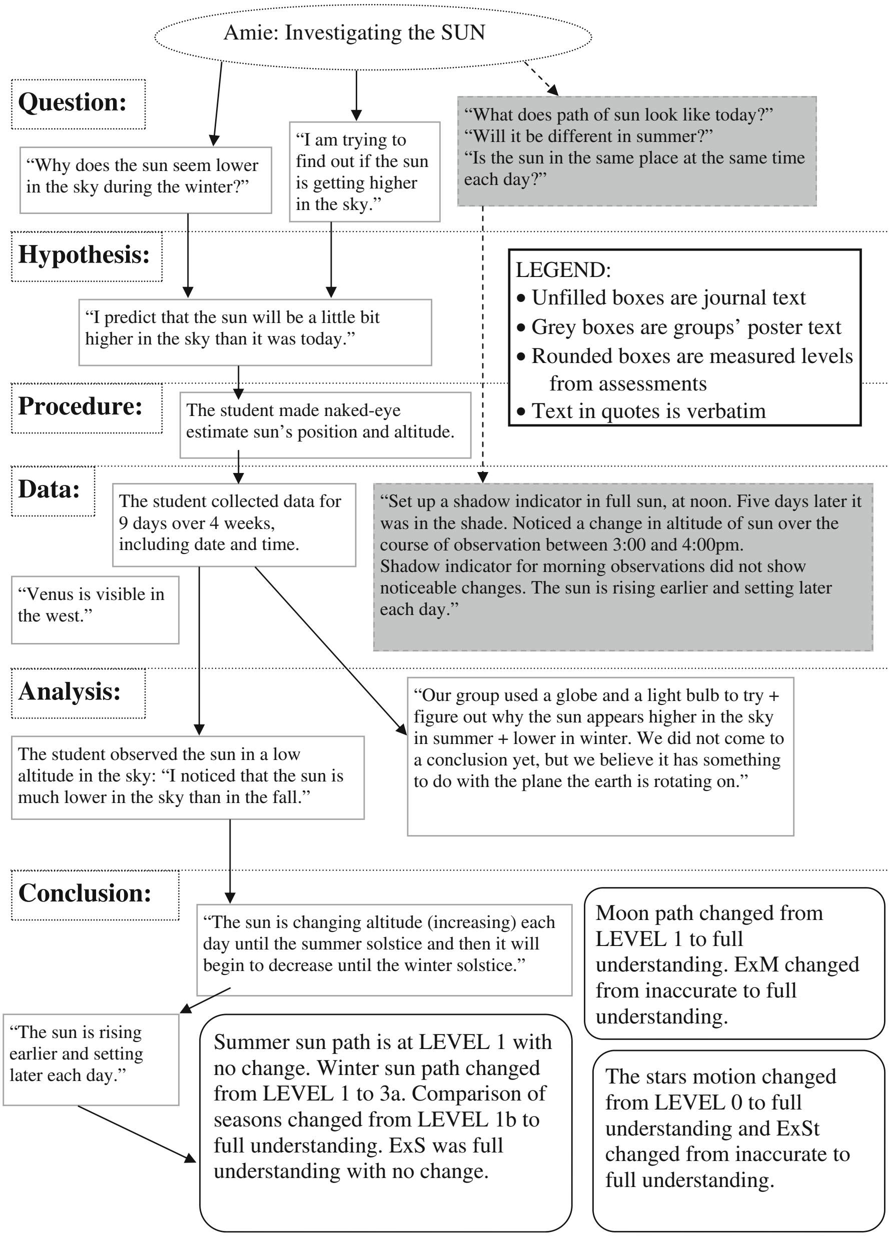

Fig. 1 Example of a flowchart created to facilitate analysis of student journals

began with a series of questions about apparent motion within a small dome representing the sky (Plummer 2009a). Within this dome, the participant used a flashlight to demonstrate his or her ideas about apparent celestial motion. The interviewer (first author) drew diagrams of the paths demonstrated. Participants then used small plastic models of the sun, earth, and moon to explain their descriptions of apparent motion (Appendix 2). Interviews were audio and videotaped.

Building upon previous research in this area (Atwood and Atwood 1995; Baxter 1989; Plummer 2009a, b) and analysis of the domain, categories were defined for the patterns of motion of the sun, moon, and stars, and the moon's changing appearance as well as explanations for the daily motion of celestial objects (Table 1). For each category, codes were created to represent a 'scientific,' 'partially scientific,' and 'non-normative' description or concept. These descriptions were refined during the coding process to account for unanticipated responses. Two of the authors separately coded all of the written assessments and interviews, while periodically discussing the rating system to improve the clarity and specificity of each code. Interview data was used to improve our interpretation of the written responses. The final comparison resulted in an inter-rater agreement of 92.6%.

Using the individual categories for each major conceptual area (e.g., the sun's path in summer is a major conceptual area) we developed a set of levels for each major concept from no understanding of the concept to the highest level of scientific understanding measured by our assessments (Table 1). The levels were constructed using a Guttman scale (Wilson 2005) because we value the positive attributes of the participants' understanding which may lead to more sophisticated levels of understanding (Duschl et al. 2007; Plummer and Krajcik 2010; Smith et al. 2006). A participant demonstrates understanding of concepts at the level she is assigned, and those below it, but not concepts designated to higher levels. For example, from the study's location (lat = 40 deg N), the sun's apparent motion in the summer is a smooth curve that rises north of east, passes below the zenith towards the south, and sets north of west. The most common description of the sun's path expressed by children includes the basic idea that the sun's path is a smooth curve, but not the scientific knowledge of the actual rise/set position, noontime altitude, or angle of the path (Plummer 2009a). A more sophisticated level would include one or two of these additional conceptual pieces (highest altitude below the zenith at our latitude or rise/set is northeast/northwest) placing the participant at a more scientific level.

Content analysis of documents was used to explore the impact of the participants' own line of inquiry on the individual's understanding (Glesne 2006). We compared the record of each participant's personal inquiry project, using the previously defined flowcharts, with the changes in understanding (as determined by their assessments).

Findings

Research Question 1: Student Inquiry Projects

Types of Investigations

Participants' investigations were classified according to their conceptual focus and a methodological focus (Table 2). Though each participant investigated the same celestial object (sun, moon, or the stars) as the rest of their self-selected group,

Table 1 Levels of celestial motion understanding

Concept	Levels	Description
Path of the sun (summer or winter)	0	Sun rises/sets but path is non-normative
	1	Path of the sun is a smooth curve across the sky (Spath)[a]
	2a	Spath and passes at least 15 degrees below the zenith (Szen)
	2b	Spath and rises/sets at least 15 degrees (north for summer; south for winter) of east/west (Shor)
	3a	Spath, Szen, and Shor all scientific
	3b	Spath, Szen, and path is tilted at an angle towards the south (Sang)
	4	Spath, Szen, Shor, and Sang all scientific
Comparison of the seasons	0	No difference between the paths in summer and winter
	1a	Sun at least 15 degrees lower at noon in winter compared to summer (Calt)
	1b	Rising/setting position of the sun is shifted at least 15 degrees when comparing summer to winter (Chor—Partially scientific (PS)) and may include the accurate shift is towards the south (scientific (Sci))
	2a	Chor (PS) and Summer sun's path is at least 15 degrees higher than the winter path (Clen—PS) or up to 30 degrees (Clen—Sci), showing a difference in the length of the paths
	2b	Rising/setting position of the sun is shifted at least 15 degrees *towards the south* when comparing summer to winter (Chor—Sci) and Summer/winter paths are separated by *at least 30 degrees* (Clen—Sci)
	3	Calt and Chor (PS or Sci)
	4a	Calt and Chor (PS or Sci) and Clen (PS)
	4b	Calt and Chor (PS or Sci) and Clen (Sci)
	5	Calt, Chor, and Clen all accurate
Path of the moon	0	Moon does not appear to move or student does not know
	1	Moon appears to move (Mmv) but no description or inaccurate description
	2	Mmv and the moon is a smooth path across the sky (Mpath)
	3	Mmv, Mpath, and moon moves in the same type of path as the sun (Msun)
Apparent motion of the stars	0	The stars do not move
	1	The stars appear to move (Stmv)
	2	Stmv and the stars appear to move in a path similar to the sun, stated OR demonstrated (Stpath—PS)
	3	StMv and the stars appear to move in a path similar to the sun, stated AND demonstrated (Stpath—Sci)
	4	Stmv, Stpath (PS), and we see different stars through the night (StDif)
	5	Stmv, Stpath (Sci), and StDif
Explanation for the motion of the sun	0	Inaccurate explanations for why the sun appears to move
	1	Inaccurate use of earth's rotation
	2	The rotation of the earth

Table 1 continued

Concept	Levels	Description
Explanation for the motion of the moon	0	Inaccurate explanations for why the moon appears to move
	1	Inaccurate use of earth's rotation
	2	The rotation of the earth
Explanation for the motion of the stars	0	Inaccurate explanation or stars do not appear to move
	1	The earth's orbit or unclear use of earth's motion
	2	The rotation of the earth

[a] Category labels are indicated in parentheses after the description of the accurate code

participants had individual questions within that domain. Group A discussed different ways of measuring changes in the sun's path across the seasons. Group B focused on changes in the moon's path from night to night. Group C also investigated the moon but projects included a range of individual topics (e.g., lunar phases, the face of the moon, rising and setting times). Group D was organized around investigations of the stars' nightly apparent motion and changes across the seasons. In class, group discussions influenced how some of the investigations progressed by helping to focus the questions and observations through shared observing techniques.

We examined the range of investigative approaches implemented by the participants. Unsurprisingly, due to the nature of the domain, most participants (89%) chose to investigate attributes of celestial objects that change over time (such as the changing altitude of the sun's path or the changing appearance of the moon). Nearly all of the participants (94%) employed qualitative methodologies, using words or drawings to record data and describe changes, while fewer (28%) used quantitative methods to record and analyze measurements. Many of the participants (72%) maintained their original investigation methods while some (28%) chose to try new methods during the investigation (either through failure to capture data that would aid in answering their questions or discovery of better methods from classmates). All of the participants recorded primary data sources (their own data collection through first-hand observation) while seven (39%) also consulted secondary data sources such as online records of the sun or moon's positions or a classmate's data. Many participants (67%), in addition to looking for data, also found conceptual help through print and Internet resources.

Investigation Challenges

Several challenges arose during the investigations based on the nature of the investigations and the organizations of the groups. The investigation questions prompted some participants (39%) to invent ways to track the motion or appearance of the sun, moon or stars such as measuring the sun's shadow as cast by a pole, taking photographs of the sun's position, inventing a rudimentary sextant to record star altitudes, or using binoculars to aid in drawing the moon. Challenges in creating and using observing aids prompted participants to refine and revise their methods as they

Table 2 Investigation groups with focus questions for individual investigations

Group A: Sun investigations	Group B: Moon investigations
Anne: Does the position of the sun vary with the season over time? Does the sun change position when observed day to day at the same time from the same observer point?	*Beth*: Does the moon rise and set?
Abby: Does the position of the sun at noon change?	*Bill*: What is the orbit of the moon?
Amie: Why does the sun seem lower in the sky during the winter? I am trying to find out if the sun is getting higher in the sky	*Brenda*: How does the height [of the moon] vary?
Aaron: Does the sun rise more toward the east the more the year goes towards summer? Does the sun get higher in the sky the more the year moves towards summer?	
April: What does the path of the sun look like today? Will it be different in the summer? Does the path of the sun change as days become longer/shorter over the course of the year?	
Group C: Moon investigations	**Group D: Star investigations**
Caitlin[a]: I will be observing the appearance and location of the month. I predict that the moon will be viewed at the same position at approximately the same time of day. I believe this will occur regardless of phase	*Darla*[a]: [I predict that] the stars will be in the same place each night at a given time. (Tracking the position of Orion.) [I predict that] the moon will not be in the same place each night at a given time
Cara: How long does one full phase last (from new moon to new moon)? What do phases say about earth's placement between sun + moon?	*Dawn*: Does the north star move? [The] earth is on two different sides of the sun, you see different stars at different times of the year. And then I started to think that because the earth is on different sides of the sun that the North Star is going to move up and down in the sky
Carla: Why does the moon have phases?	
Chelsea: Do we only see one side of the moon?	
Claire: Does the moon move in same path every night?	
Crystal: What causes the change in the moon's rising and setting times? I was told we always see the same face of the moon—even though it orbits the earth & rotates (I think). How does this work? I am also interested in the moon's location in the sky. Why does it change?	*Diane*: Do the stars appear to move? Exactly how much they move I do not know; therefore I will be tracking the placement of the constellation Orion throughout the early hours of the evening.
	Dee: Is the earth moving more than [the] stars? The student used a washer on a string to chart the altitude of Orion

Note: Words placed in brackets were added or changed to improve the clarity

[a] Predictions are included for participants who did not write questions

progressed. Participants in Group A (The Sun) initially struggled to develop ways to collect data that would allow them to track seasonal changes in the sun's path. Anne began by recording the sun's rising position in relation to distant buildings through drawings in her notebook, but soon abandoned this method because she could not continue to be at that observing point every day. After finding that the trends in her measurements differed from others' measurements in her group, Anne questioned the accuracy of her data collection methods, which prompted her to begin taking photographic records in addition to marking the position of a shadow on a board at a specific time. Her group-mate Abby also discovered that after a few observations she could no longer use her initial location; the sun had shifted and another object cast a shadow across her apparatus. Chelsea tried multiple methods to determine whether or not we only see one side of the moon. Her attempts with naked-eye observations and photography did not produce results detailed enough to answer her question. She then combined photographs found on the Internet with her own binocular-aided drawings to answer her research question.

Two groups were able to find the connections between individual group member's questions while the other two groups struggled due to diverse questions and methods. The participants who investigated the seasonal change of the sun's path (Group A) were able to successfully compare and integrate their questions and observations during the classroom discussions and poster presentations. Group D integrated three members' investigations relating to the apparent motion of the constellation Orion and Dawn's investigation of the North Star. Part of the success of the integration in this group may have been because of Dawn's relatively high content knowledge. The lunar-oriented investigations of Groups B and C integrated less successfully. Group B discussions and poster-presentations primarily focused on Bill's data and methods. This may have been the result of the differences in the data collected by each member. Beth and Brenda used a qualitative approach in recording times and directions for the moon. Bill collected extensive data on the moon's position, altitude, and phase, partly aided by the U.S. Naval Observatory Web site, using a highly quantitative approach. The large difference between methodological approaches in the group may have been the reason why Beth and Brenda allowed Bill's research to dominate the content of their presentations. Participants in Group C investigated and presented a wide range of questions relating to the moon's face, phases, locations in the sky, and rise/set times. These participants did not demonstrate an understanding of the connections between the data collected by all group members. Without deep content knowledge, Group C's members were not able to find the connections between the topics on their own.

Finally, participants attempted to find explanations for their observations with minimal assistance from the instructor and limited class time allocated to this task. Only eight (44%) of the participants wrote about their attempts to formulate an explanation for the patterns they uncovered in their investigations. Anne and Crystal wrote about their groups' attempts to formulate explanations based on scientific models while Diane wrote about information she learned from a group member that helped her understand her topic area. This level of sharing of ideas and collaborative development of explanations was not seen in the other participants' journals. This suggests that science methods students may need more structure and support to fully utilize the collaborative structure of small group investigations or to develop their own explanations for the patterns they observed. However, the written journal only captured what they chose to record. Explanations were discussed in greater detail verbally in class.

Research Question 2: Post-Instruction Understanding of Celestial Motion Concepts

Participants' Initial Understanding of Celestial Motion

Pre-assessments indicate that celestial motion was not well understand by most participants (Table 3). Most participants (94%) inaccurately described the sun's motion in summer as through the zenith while fewer (44%) also believed that the sun passes through the zenith in winter. Half knew that the sun's path shifts towards the south in the winter, becoming a shorter path across the sky (50%), though only seven participants (39%) clearly indicated that the sun appears higher in summer compared to winter. Five participants did not believe that the moon appears to move (28%) and another four participants (22%) knew that the moon appears to move but could not describe that apparent motion. Only seven participants (39%) accurately described the moon's path as a smooth curve across the sky. Half of the participants (50%) did not believe that the stars appear to move at night. Only four participants (22%) accurately stated that we see different stars throughout the night.

Only Bill and Dawn demonstrated understanding that the earth's rotation explains the basic daily motion of the sun, moon and stars. Eleven participants (61%) accurately used the rotation of the earth to explain the sun's apparent motion. The remaining participants gave alternative explanations, such as the earth's revolution around the sun or combing the rotation of the earth with the earth's revolution.

Table 3 Number of participants at each level of pre-instruction understanding ($N = 18$)

	Levels					
	0	***1***	***2***	***3***	***4***	***5***
Path of the sun in summer	0	15	2 (2 @ 2b)	0	1	
Path of the sun in winter	0	8	3 (3 @ 2a)	7 (6 @ 3a; 1 @ 3b)	0	
Comparison of the sun's path across the seasons	7	6 (2 @ 1a) (4 @ 1b)	0	1	2 (2 @ 4a)	2
Path of the moon	5	4	1	7		
Apparent motion of the stars	9	2	0	0	3	4
Explanation of the sun's motion	6	1	11			
Explanation of the moon's motion	13	1	4			
Explanation of the stars' motion	8	3	7			

Note: Shaded areas are levels that do not exist. For example, Level 4 is the highest for the path of the sun and Level 2 is the highest for the explanation for the sun. Level 0 represents no understanding of the accurate description or concept

A smaller portion of the participants accurately explained the moon's apparent motion (22%) or stars' apparent motion (39%) using the earth's rotation, partly because many participants did not believe that these celestial objects appear to move.

Overall Change in Understanding After Investigations

We examined the change in understanding to uncover how the participants' diverse investigation experiences changed their overall understanding of apparent and actual celestial motion. Table 4 shows the number of participants who improved, regressed, and stayed the same in their descriptions and explanations of the patterns of apparent motion. The areas that showed the most improvement were in their descriptions of the patterns of celestial motion: ten participants (56%) improved their description of the stars' apparent motion, nine participants (50%) improved their descriptions of the change in the sun's path across the seasons, and eight participants (44%) improved their descriptions of the sun's path in winter and the moon's apparent motion. Eight participants also improved their explanation of why the stars appear to move. Most participants (67%) did not improve their explanation of why the sun appears to move; however, 10 of these 12 already had the full scientific understanding before instruction began. Five participants (28%) did not give the scientific explanation for the sun's apparent motion at end of this investigation. The explanation of the moon's apparent motion remained an area that few participants understood. After their investigations only five participants (28%) explained the moon's apparent motion using the earth's rotation and two of these participants gave that explanation before the investigation. The remaining participants were more likely to use the moon's actual motion to explain the apparent motion.

Connection Between Investigations and Change in Understanding

In examining change in understanding across the instructional period, we looked for improvement both in the conceptual area of the participant's investigation and the

Table 4 Impact of inquiry investigation on participants' descriptions ($N = 18$)

	Improved	Regressed	No change (# of participants accurate initially)
Path of the sun in summer	7	1	10 (0)
Path of the sun in winter	8	2	8 (0)
Comparison of the sun's path across the seasons	9	4	5 (1)
Path of the moon	8	0	10 (7)
Apparent motion of the stars	10	4	4 (2)
Explanation of the sun's motion	4	2	12 (10)
Explanation of the moon's motion	3	3	12 (2)
Explanation of the stars' motion	8	0	10 (7)

Table 5 Relationships between areas of investigation and areas of improved understanding

	Improvement in conceptual area of investigation	No improvement in conceptual area of investigation
Improvement in non-investigation concepts	Amie, April, Aaron, Carla, Chelsea, Claire, Crystal, Dee, Darla	Beth, Brenda[a], Bill[a], Cara, Dawn[a,b], Diane[a]
No improvement in non-investigation concepts	Abby	Anne, Caitlin[b]

[a] Participant began and remained at full understanding of concepts under investigation

[b] Participant began and remained at full understanding of a concept area not under investigation

remaining areas that were not part of their investigation. Table 5 shows, for each participant, whether they improved in their area of investigation and/or improved in other conceptual areas. No relationship was found between the topic that the participant chose to investigate (sun, moon, or the stars) and where they fell on the improvement grid (Table 5). Only for Group B did we find the same relationship between investigation and improvement across the members of the group: these three participants did not show improvement in their investigation topic, as measured by the coding procedures used with the assessments, but did improve in other topics. More participants improved in areas that were not part of their investigation (83%) than showed improvement in their area of investigation (56%). However, four participants began with full understanding of their conceptual area of investigation according to our assessment levels. The following sections describe the trends we found when we examined the relationship between the investigations, classroom instruction, and areas of improvement for these participants.

Improvement in investigation topics: Ten participants (56%) (Groups A, C, and D) improved in areas that related to their investigation topic as measured by our assessment. Amie, Aaron, Abby, and April investigated the change in the sun's path across the seasons; their final assessment showed that all improved their description of this seasonal change. Carla, Claire, Chelsea, and Crystal each investigated a different question about the moon. All improved their description of the moon's daily path across the sky, though none improved their model of why the moon appears to rise and set. And while Carla and Crystal did not reach a fully scientific description of the moon's phases, Claire's investigation of why we see the same face of the moon led to a sophisticated explanation of why this occurs in her journal. Both Dee and Darla's investigation of stars' apparent motion led to improvement of this conceptual area. Before Darla's investigation she knew that the stars appear to move, and that the earth rotates to cause day and night, but did not use the earth's rotation to explain the stars' motion. Dee did not think that the stars appear to move. Both participants tracked the position of Orion over the course of the investigation and improved their ability to describe and explain the stars' apparent motion.

Improvement in non-investigation topics: Fifteen participants (83%) improved in categories that were not specifically part of their investigation. Coverage of these topics during class may account for improvement, such as specific observational and modeling opportunities (described in Methodology). For example, the whole group discussed an in-class observation of the sunset and full moon with respect to these objects' apparent motion. Participants also made observations of the sky as part of their investigations that may have contributed to their understanding of other categories; for example, while making observations of the moon they may have had additional opportunities to consider the stars' apparent motion. Groups gave presentations to the whole class about their observations and explanations. The group investigating the stars gave a clear and detailed presentation on their topic; this may help explain why the star concepts showed the most improvement in the post-assessments.

No measured improvement: Participants may have chosen to investigate concepts where they already held a higher level of understanding. Thus, ceiling effects may help explain why eight of the participants did not show improvement in their investigation topic (however, six of these participants did show improvement in other concept areas). Four participants (Dawn, Diane, Bill, and Brenda) held the full understanding of their investigation target, as measured by the assessment. Yet for each of these participants, analysis of their journals and poster presentations suggests that their understanding in their investigation topic may have improved beyond what was measurable by our interviews and surveys. For example, Diane writes: "I have concluded that… [because] the earth rotates, tilts, and orbits, Orion appears to be in a different place at different times throughout the night and year. Orion is only visible during the winter because he is located on one side of the sun; the side that the earth is on during winter." Earlier, Diane indicated that she believed that Orion would "appear to move only because the earth is rotating" rather than also changing due to the earth's orbit.

Neither Anne nor Caitlin showed improvement, as measured by the assessments, in any category. However, Caitlin began with full understanding of the stars concepts, thus limiting areas for which we could measure improvement (Anne also began with a high level of understanding of star concepts). An examination of Caitlyn's journal and the interview with Anne reveals areas of improvement not captured in our initial analysis. During Anne's pre-instruction interview, she indicated that there is no change in the sun's path across the seasons. In her post-instruction interview, she indicated that she learned through her investigation that the sun's path shifts during the seasons. Her data indicated that the sun's rising position shifts towards the north from winter to summer but she lacked data for the shift in the setting position. She erroneously concluded that the sun's setting path shifts south from winter to summer (rather than understanding that the sun's path is shorter in winter compared to summer). While not a complete improvement, this indicates that Anne now knows that there is a seasonal change in the sun's path. Caitlin initially predicted that the moon would appear in the same place in the sky at the same time every night. During her subsequent investigations, she wrote in her journal:

> I was not able to observe the moon tonight at my set time. When I looked toward the east, I expected to see it illuminated. I went back to the U.S. Naval Observatory link and read that the moon did not rise until 8:59 p.m. This disproves my hypothesis that the moon will be in the same position everyday at the same time. (Caitlin)

While it is not clear if she has mastered the full pattern of motion, she went beyond her initial understanding in a way that was not measured by assessments.

Discussion

Previous studies have shown that many preservice and inservice teachers do not accurately understand elementary-level astronomical concepts (Atwood and Atwood 1995; Mant and Summers 1993; Parker and Heywood 1998; Trundle et al. 2002). Our analysis adds to this body of work by suggesting that many preservice teachers do not hold scientific concepts of the patterns of the sun, moon, or stars' daily motion or the seasonal change in the sun's path, and cannot give scientific explanations for these patterns, especially for the moon and the stars. This limited understanding is likely to have a negative impact on their future astronomy teaching, especially in more advanced topics taught in elementary schools, such as phases of the moon and the seasons, which build on these concepts.

Through an inquiry investigation of celestial motion, set in a science methods class, most participants (89%) increased their level of understanding of some aspects of celestial motion; journal entries and interview data suggest the remaining participants improved their understanding in ways that were not uncovered by our other assessment methods. Within this open-inquiry model of learning astronomy, participants chose the questions they wished to learn more about; the answers to these questions did not necessitate understanding all aspects of celestial motion. Thus, it is not surprising that participants did not improve in all measured areas and that, given the observational focus of their projects, the major areas of improvement were in the participants' descriptions of celestial motion, rather than their explanations of observed phenomena. However, many participants also improved in areas outside of their own investigation, which often corresponded to topics discussed in class through demonstrations or other participants' presentations.

While the use of an open-inquiry experience produced positive results (increased understanding of celestial motion and the opportunity for participants to engage in inquiry practices) our findings also suggest that preservice elementary teachers are not likely to develop a full understanding of celestial motion from this instructional design. Even though most participants began with an accurate explanation for the sun's daily motion, the investigations did not result in all participants providing an accurate explanation of this phenomenon. After these investigations, there remained participants who believed that the sun revolves around the earth or that the moon appears to rise each day because of its orbital motion. The group investigating the seasonal change of the sun's path struggled with both the sun's apparent motion and the explanation for the change; they did not reach the full scientific understanding of the seasonal change in the sun's apparent motion or the explanation for these changes.

The participants' limited success in applying scientific models to explain their data suggests that teacher educators may need to provide more guidance to help preservice teachers perform these practices. While providing an opportunity for open-inquiry at the beginning of an investigation of celestial motion lead many participants to improve their ability to describe aspects of celestial motion, more guidance may be necessary at the conclusion of the investigation. This could include more directed guidance towards explanations and assistance in using these explanations to address the observational data (Vosniadou 1992), especially for concepts that are foundational for understanding more sophisticated concepts (including the use of the earth's rotation to explain the sun, moon, and stars' daily motion and the moon's slow orbit). Intensive model-based reasoning activities linked to their own investigations may move students beyond what they are able to construct on their own (Duschl et al. 2007). Previous studies of preservice teachers participating in guided investigations of the seasons and phases of the moon (Trumper 2006; Trundle et al. 2006) found an increased ability to explain these phenomena after guiding students in analysis of their observations in conjuncture with modeling of the motions of the earth and/or moon with respect to the sun. Guided modeling may help bridge the gap for students who have asked relatively advanced questions with limited background knowledge to support a sophisticated analysis.

Beyond new conceptual understanding of astronomy, analysis of the journals showed that most participants practiced the skills associated with beginning an inquiry investigation by formulating their own question and designing techniques to aid in their observing projects. Participants focused on using their observations to uncover patterns in nature. The preservice teachers in this study were creative in the range of scientific questions and methodologies they chose though most did not choose quantitative approaches. Preservice teachers who participate in open-inquiry experiences believe they will use similar experiences with their future students (Morrison 2008). Thus, we hope that this experience will encourage these future teachers to seek out new resources to aid in investigations, develop observational tools, ask scientific questions, or look for patterns as part of science in their future classrooms. However, preservice teachers may require additional scaffolding in their groups towards collaborative efforts to make connections between their separate investigation topics. While the participants in this study had opportunities to collaborate in class, the results of these collaborations rarely appeared in their science notebooks. Specific prompts that require the use of group-mates' ideas may elicit writing that reflects the reasoning process as well as the collaborative process.

Our study of preservice teachers doing inquiry compliments previous studies, which investigated the impact of inquiry experiences on understanding of the nature of science. Rather than focusing on what they were learning in terms of the nature of science, we were able to identify the ways in which participants were learning astronomy in an open-inquiry environment. As with Morrison's study of preservice elementary teachers (2008) and Melear et al.'s (2000) study of preservice secondary science teachers, our participants conducted a long-term open-inquiry investigation, working both independently and collaboratively. In addition to supporting their growth in understanding of the nature of science and learning to work cooperatively (Melear et al. 2000; Morrison 2008), open inquiry can improve preservice teachers' awareness of astronomical phenomena and increase the accuracy of their descriptions and, to a limited extent, their explanations. While, Abell et al. (2001) found that elementary science methods students who investigated the moon for 6 weeks also improved their understanding of the nature of science to a certain extent, explicit instruction is necessary to improve across all dimensions of the nature of science (Abd-El Khalick and Lederman 2000). These studies, along with our findings, suggest that if our goals include both conceptual knowledge and understanding of the nature of science, preparing teachers requires opportunities for open-ended inquiry where participants struggle through the frustrations of doing science, explicit instruction on how this models the nature of science, and additional guidance in constructing scientific models to improve their understanding of conceptual goals.

Implications for Future Research

Future studies are needed to investigate how additional guided inquiry opportunities may improve preservice and practicing elementary teachers' understanding of the patterns and explanations of celestial motion. Recent work using computer-based astronomy programs (Bell and Trundle 2008) and the planetarium (Plummer 2009b) suggests the use of technology can assist learners in understanding celestial motion. Future research comparing the use of technology as an investigation aid to other conventional approaches could uncover new ways of supporting teachers. If an open-inquiry approach begins the investigation, a more structured in-class modeling of the whole sun-earth-moon system may be necessary to improve overall understanding of these concepts. However, such an approach is likely to increase the amount of classroom-time spent on these topics. Thus, the likelihood that such an approach will be used is low due to the limited time available to devote to all aspects of science education for preservice teachers (National Commission on Teaching and America's Future 1996).

This suggests that research is needed to identify a balanced approach, which will improve preservice teachers' conceptual understanding while also increasing their science process skills around inquiry. Given that it is unlikely that most teachers will have extended opportunities in undergraduate astronomy courses or science methods courses, can we design educative curriculum materials (Davis and Krajcik 2005) on celestial motion that gives teachers the support they need to learn these concepts while also teaching them? We hope further studies will be conducted on teachers' use of carefully designed, inquiry-based, educative astronomy curriculum materials and the impact of such a curriculum on the teachers and students' understanding of the concepts and the nature of science.

Acknowledgments The authors gratefully acknowledge the assistance of Amanda Penecale with reviewing the analysis of student journals and Erica Davila and Peter Appelbaum for comments on an early version of this manuscript.

Appendix 1: Celestial Motion Survey

Write your name on this sheet AND on the plastic hemisphere. For each of the paths you draw on the plastic hemisphere, if the object is "rising" write **rise** at the beginning of the path and write **set** at the end of the path. You can also use arrows to indicate the direction of an object's motion. For your written answers, please use drawings and written descriptions when needed.

1. Imagine it is the first day of summer. Does the sun appear to move in the sky? On the plastic hemisphere, draw the apparent path of the sun in the sky starting from when it rises to when it sets. Use the RED pen. Write **noon** for the sun's position at noon. Explain why you would see that motion of the sun.
2. Imagine it is now the first day of winter. Is there any difference in the path of the sun compared to summer? If so, draw the sun's path in winter in BLUE. Write **noon** for the sun's position at noon if it is different in winter. Are there any other differences between summer and winter?
3. Why do we have day and night? Please use diagrams to help explain your answer.
4. Can we ever see the moon during the day? If yes, what time of day?
5. Now imagine the moon in the sky. Does the moon appear to move? If so, draw this path on the dome in GREEN. If you cannot draw its path, explain why. If you drew the moon's motion on the hemisphere, explain why the moon appears to move in the sky. Are there times when we cannot see the moon in the sky? Explain why.
6. How long does it take for a full cycle of phases of the moon?
7. Why can't we see the stars during the daytime?
8. Do the stars appear to move at night like the sun moves during the day? Why or why not? If you think that stars appear to move in some pattern during the night, or day, use the BLACK pen to show this on the hemisphere.
9. Do we see the same stars all night long? Why or why not?

Appendix 2: Interview Questions Using Physical Models

Have the student put a sticker on the earth to show his/her location.

1. Can you use these objects to explain why the sun appears to move across the sky as you showed in the dome? (Prompt the student to indicate sunrise, noon and sunset.)
2. Can you use these objects to explain the differences in what you showed between the summer and the winter?
3. Can you use these objects to explain why the moon appears to move (or not move) like you showed in the dome?

    a. Can you use these objects to explain why there are times we cannot see the moon?

4. Where would the stars be in this model? When would we be able to see them?
5. Can you use these objects to explain why stars (do not) appear to move?

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