

Inquiry and Astronomy: Investigations in Celestial Motion

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Abstract

This study investigated the impact of an open inquiry experience on elementary science methods students' understanding of the apparent motion of the sun, moon and stars and their explanations for these motions. Each student in the class (N=18) chose a range of questions to investigate for their inquiry projects, all in the domain of celestial motion. Students' were given pre- and post-instruction assessments to measure change in understanding and their science journals were analyzed for further evidence of the correlation between their chosen topic and change in understanding. Analysis reveals that these students do not hold scientific understandings of the patterns of apparent motion of the sun, moon and stars and that while most students used the rotation of the earth to explain the apparent rising and setting of the sun, they did not use this to explain the apparent motion of the moon and stars. A comparison of individual students' inquiry projects with the change in their understanding reveals that while most students improved in both their area of inquiry and beyond, students will need more structured instruction to reach a full scientific understanding across all aspects of celestial motion. This study has implications for future teacher training, K-12 astronomy instruction and the design of educative curriculum in astronomy.

Introduction

The purpose of this study was to investigate pre-service elementary teachers' ability to explain the apparent motion of the sun, moon and stars using the actual motion of the earth and moon and the impact of their own inquiry investigations into these topics on that understanding. Scientific knowledge of apparent celestial motion includes understanding how to describe the sun's rising and setting motion across the seasons, the moon's rising and setting motion, and the stars' apparent rising and setting throughout the night. All of these motions can be explained by the slow rotation of the earth on a daily basis (except for the change in the sun's path across the seasons, explained by the earth's tilt as it orbits the sun). These are concepts that are described by the National Science Education Standards (NRC, 1996) and Benchmarks for Science Literacy (AAAS, 1993) as appropriate for students to learn in elementary school.

The ability to explain observable phenomena (the apparent motion of the sun, moon and stars, the day/night cycle, seasons, phases of the moon) using the actual motions of the objects involved (earth, moon, sun, stars) is one of the most fundamental aspects of astronomy. If teachers are to be prepared to help elementary students develop these understandings they will need a deep and rich understanding of celestial motion as well as strategies they can use to teach these concepts. Recently, Plummer (2006) described the limitations in elementary and middle school students' descriptions of apparent celestial motion suggesting that traditional instructional approaches are not enough. However, for teachers to reach level of understanding will require the ability to visualize three-dimensional concepts and move between various perspectives in space and on earth, an ability that many learners will find challenging (Parker & Heywood, 1998). Thus, one of the goals of this study is to describe the relationship between teachers' understanding of apparent and actual motion and to analyze their ability to shift between frames of reference by using their own observations to prompt a deeper understanding of the concepts.

Prior studies investigating pre-service and in-service teachers' understanding of elementary astronomy concepts have described teachers and pre-service teachers' alternative ideas that may hinder their ability to teach children. Mant & Summers (1993) concluded that the elementary teachers in their study did not have a good observational foundation and were attempting to work from "mental models" to formulate responses. Many had alternative ideas about the apparent motion of the sun, moon and stars. A large fraction of both teachers and pre-service teachers hold alternative ideas about the explanation for why we have day and night (Atwood, & Atwood, 1995; Mant & Summers, 1993; Parker & Heywood, 1998). Few pre-service teachers are able to accurately explain the phases of the moon (Trundle, Atwood, & Christopher, 2002). Even the most introductory astronomy concepts are not well-understood by many pre-service and in-service teachers.

Beyond assessing the knowledge base of teachers, we need to put more effort into analyzing instruction designed to improve understanding (Bailey & Slater, 2003). The use of models has been found to be a successful strategy in teaching about concepts such as the day/night cycle (Atwood, & Atwood, 1997), phases of the moon (Callison & Wright, 1993; Trundle, Atwood & Christopher, 2002) and the seasons (Atwood & Atwood, 1997). The students in Trundle, Atwood, & Christopher also used a guided-inquiry approach to the instruction they investigated (2002). Their results suggest this is a successful method in improving understanding of the

phases of the moon: begin with the students’ observations of the moon followed by the use of models to explain their observations. This study also examined students learning through their own observations and use of models to explain their observations.

Elementary-level astronomy concepts are not well understood by elementary teachers (Atwood & Atwood, 1995, 1997; Mant & Summers, 1993; Parker & Heywood; 1998; Trundle, Atwood, & Christopher, 2002). Poorly developed understanding in this domain will limit teachers’ ability to design and implement instructional designs for their students. However, if pre-service teachers are able to design and implement their own inquiry investigations, with limited instructional support, and if these investigations result in improved understanding then this could support the future development and dissemination of inquiry-based elementary astronomy curriculum. This study uncovers the areas of celestial motion where pre-service teachers successfully improved their understanding and the areas that are likely to require additional instructional support. These results may help us design future inquiry-based astronomy curriculum and identify key areas to emphasize in professional development, teacher training programs, and undergraduate astronomy courses.

The following research questions guided this study:

1. Before instruction, how do elementary science methods students describe and explain the apparent motion of the sun, moon and stars?
2. What kind of inquiry investigations did students chose to pursue in an open inquiry environment?
3. In what ways did the students’ ideas change as a result of their own inquiry investigations and in-class activities?

Methodology

Participants

This study involved adult students (N=18) in an elementary science methods course at a small liberal arts college (latitude = 40 degrees North). Table 1 gives the characteristics of students in this course. Most of the students were taking the course as they worked towards an elementary education certification though three were current teachers (pre-kindergarten, sixth grade, and middle school). Sixteen of the students were registered as graduate students; the remaining two were upper level undergraduate elementary education majors. Four of the students had previously taken one or two astronomy classes. The lead author of this study was also the professor for this course.

Female	Male	Currently teaching	Pre-service teachers
16	2	3	15
Graduate students	Undergraduate students	One or more astronomy courses in high school/college	No previous astronomy courses
16	2	4	14

Table 1 – Subject Characteristics (N=18 for all rows)

Instruction

The primary purpose for including this extended investigation of celestial objects in the students' elementary science methods course was to give the students an experience of scientific inquiry as described in *Inquiry and the National Science Education Standards (INSES; NRC, 2000)*. Most elementary science teachers have had limited experiences in inquiry science environments and thus have poorly developed understandings of how to teach via inquiry. The students participated in a 9-week astronomy inquiry project, with about 30 minutes to 1 hour spent in class every other week for a total of about 200 minutes of in-class time. Most of this time was used by students to work in groups to discuss, analyze and explain their observations or to present their observations to class. Students recorded their questions, plans, observations, in-class discussions, and attempts to explain their observations in a science journal.

In the first week of the inquiry, students were asked to make start making observations that would help them determine the patterns of motion for the sun, moon and stars. We discussed what kinds of observations they might choose to make and what they predict they will observe. Students were each given a small compass to help guide their observations of directions (though the accuracy of this compass was limited). We also discussed the features of inquiry and the inquiry continuum as described in *INSES*.

In the third week, students were asked to work in groups to discuss their observations and narrow their inquiry question to one piece of observable celestial motion. Students chose groups based on their interests, resulting in one group investigating the sun, two groups investigating the moon, and one group investigating the stars. Students were asked to compare their observations, decide if they could support their predictions, and propose or refine new questions.

In the fifth week, students 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. As a wrap-up, students were asked to plan their next observations, predict what they will observe, and suggest how this will answer their questions. In the sixth week of the investigation there was a total lunar eclipse; however, it was mostly cloudy at our location.

In the seventh week, students 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. Students were given a brief lecture on some basic concepts (earth's rotation, orbit, tilt, and moon's orbit). Students were also given written explanations of the basic phenomena that they were investigating as another resource in their project but it is unknown if they read or used this (Lunar and Planetary Institute, 2007).

In the final week of the project, the students worked in groups again to make final posters and presentations of their group's projects (an example of a poster is in Figure 1). Each group was asked to find a way to combine their questions and observations. Each presentation was to include answers to the following questions:

1. What question(s) are you trying to answer or observations are you trying to explain?

2. What data did you collect?
3. What is your claim or conclusion? How do you explain your observations?

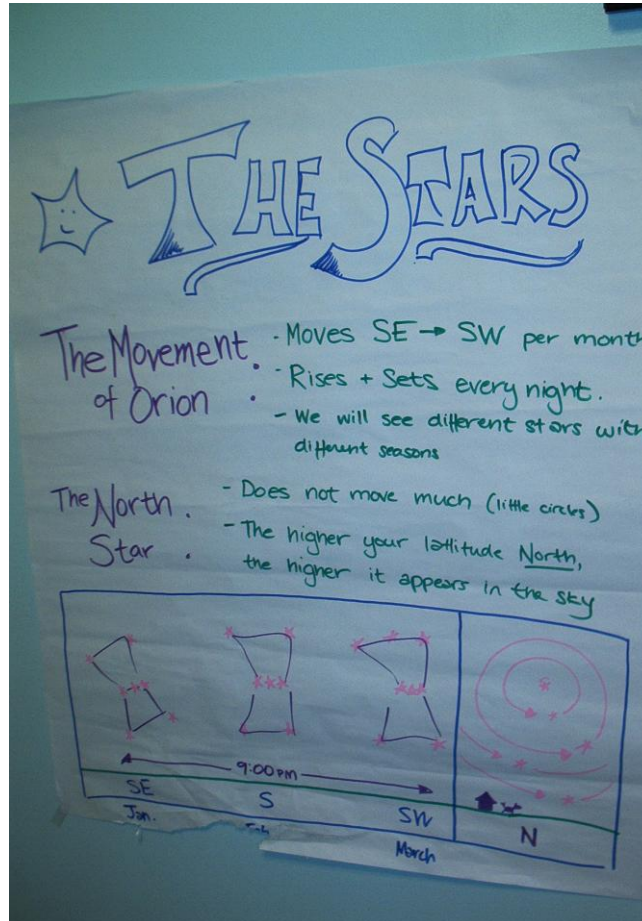


Figure 1 – Final presentation poster from Group 4

Data collection and analysis

The change in student understanding as a result of this inquiry investigation was assessed using a written survey and the students’ journal entries. All students took an open-ended, written survey that asked them to describe and explain the apparent motion of the sun, moon, and stars (Appendix 1); this survey asked the students to use a small clear plastic hemisphere on which they could draw their description of the sun, moon and stars’ apparent motion, from an earth-based perspective. Codes were developed for the patterns of motion of the sun, moon and stars, the moon’s changing appearance, and the explanations for the daily motion of celestial objects (Appendix 2). These were used to assess the scientific accuracy of responses by breaking down whole descriptions into smaller conceptual pieces. Each of these codes was labeled ‘scientifically accurate’, ‘scientifically inaccurate’, and ‘unknown.’ Two of the authors of this study separately coded all of the assessments, while periodically discussing the rating system to improve the clarity and specificity of each code. Final comparison resulted in an inter-rater agreement of 95%.

Using the individual codes for each concept area, we developed a set of levels for each major concept that ran from no understanding concept to a scientific understanding. For example, the scientific description of 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, and non-normative, understanding of the sun's path expressed by students (Plummer, 2008a and the present study) includes basic idea that the sun's path is a smooth curve, but not the understanding of the rise/set position, noontime altitude, or the angle of the path towards the south. This represents one of the lowest levels of understanding. Above this, but not yet fully scientifically accurate, would include one or two of the additional conceptual pieces (highest altitude below the zenith at our latitude or rise/set is north of due east/west) placing the student at a higher level of understanding. This description of the levels of the sun's path and the rest of the conceptual levels are described in Table 2.

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)
	2a	Spath and passes at least 15 degrees below the zenith (Szen)
	2b	Path of the sun is a smooth curve across the sky (Spath) and rises/sets at least 15 degrees north (for summer; south for winter) of east/ west (Shor)
	3a	Spath, Szen, and Shor all accurate
	3b	Spath, Szen, and path is tilted at an angle towards the south (Sang)
	4	Spath, Szen, Shor, and Sang all accurate
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 –PA or Acc*)
	2a	Chor (Partially Accurate) and/or Summer sun's path is separated by at least 15 degrees, showing a difference in the length of the paths (Clen – Partially Accurate or Accurate)
	2b	Rising/setting position of the sun is shifted at least 15 degrees <i>towards the south</i> when comparing summer to winter (Chor – Accurate) and Summer & winter paths are separated by <i>at least 30 degrees</i> (Clen – Accurate)
	3	Calt and Chor (partially accurate or accurate)
	4a	Calt and Chor (partially accurate or accurate) and Clen (Partially Accurate)
	4b	Calt and Chor (PA or Acc) and Clen (Acc)
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 drawn) (Spath – PA)
	3	StMv and the stars appear to move in a path similar to the sun (stated AND drawn) (Spath-Acc)
	4	Stmv, Spath (PA), and we see different stars through the night (StDif)
	5	Stmv, Spath (Acc), 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
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

* PA: Partially Accurate; Acc: Accurate

Table 2 – Levels of Apparent Celestial Motion Understanding

A mixed-methods approach was used to explore the impact of the students' own line of inquiry on the individual's understanding. Each student chose their own question(s) to explore within the domain of celestial motion. Through observational experience and work in their small groups students refined their questions and observing strategies. Throughout the 9 weeks, students recorded their observations and in-class work in their science journal. This journal was used as a source of information on the extent of their inquiry project, as well as two poster presentations they made in class. We compared the extent of each student's personal inquiry project with the changes in understanding (as determined by their assessments). To aid in this comparison, a flowchart was created for each of the students' science journals. The flowcharts track the progression of the student's investigation and make connections between the concepts written about in their journal and their change in understanding as shown in the pre/post assessment. In this way we were able to uncover how their investigation changed their understanding of celestial motion.

Findings

Students' Initial Ideas

In the analysis, the students' initial ideas about the apparent motion and the explanation of that motion were placed on levels ranging from no understanding to the highest level of scientific understand as measured on our assessment (Table 2). The apparent celestial motion of the sun, earth and moon and how to explain those motions are not well understood by these science methods students. Most students (89%) inaccurately described the sun's motion in summer as through the zenith while half (50%) also believed that the sun passes through the zenith in winter. The majority of students knew that there is a difference between the sun's altitude in summer and winter (67%), though only six students (33%) understood that the sun's path shifts towards the south in the winter, becoming a shorter path across the sky. Six students (33%) did not demonstrate understanding of the change in the sun's path. This more advanced knowledge of the sun's path is important for explaining why we have seasons, a commonly misunderstood topic among children and adults (e.g. Atwood & Atwood, 1996; Baxter, 1989).

Most of the students had a very limited understanding of the moon and stars' apparent motion. Five students did not believe that the moon appears to move (28%) and another seven students (39%) knew that the moon appears to move, but could not describe that motion. Only six

students (33%) could give a reasonably scientific description that the moon's path is a smooth curve across the sky (though this does not consider any of the more complex patterns of the moon's rising and setting motion such as the shift in when it rises/sets or how its highest altitude changes over its orbital period). Half of students did not believe that the stars appear to move at night. Four students gave a limited description of that motion or at least knew that the stars appear to move. Only five students (28%) could accurately state that we do see different stars throughout the night, an idea that arises logically from understanding the earth's rotation.

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

Note: Shaded levels are those 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.

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

The earth's rotation explains the basic daily motion of the sun, moon and stars. However, as indicated above, while all students understood at least the simple description of the sun's apparent motion (those ideas not complicated by the shape of the earth or tilt of the earth's axis) many did not believe that the moon or stars appear to move. Eleven students (61%) students used the rotation of the earth to explain the sun's apparent motion, while an additional student inaccurately used the earth's rotation to explain the sun's daily motion. The remaining six students gave alternative explanations, consistent with results of previous studies on teachers explaining why we have day and night (Callison & Wright, 1993; Atwood & Atwood, 1995).

A much smaller portion of the students used the earth's rotation to explain the moon or stars' apparent motion, partly because many students did not believe that these celestial objects appear to move from our perspective. Only five (39%) students explained the moon's apparent motion

as well as the stars' apparent motion with the earth's rotation (these were not all of the same students). The majority of students gave inaccurate explanations to why the moon and stars appear to move or inaccurately used the earth's rotation. Overall, only three students (17%; students 110, 112, and 113) used the earth's rotation to explain the daily apparent motion of the sun, moon and stars. These results suggest that most elementary teachers do not have the scientific understanding of elementary level astronomy concepts of celestial motion.

<p>Group 1: Sun investigations</p> <p>101: 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?</p> <p>105: Does the position of the sun at noon change?</p> <p>111: 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.</p> <p>113: 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?</p> <p>119: 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?</p>	<p>Group 2: Moon investigations</p> <p>102: Does the moon rise and set?</p> <p>110: What is the orbit of the moon?</p> <p>117: How does the height [of the moon] vary?</p>
<p>Group 3: Moon investigations</p> <p>103^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</p> <p>104: How long does one full phase last (from new moon to new moon)? What do phases say about earth's placement between sun + moon?"</p> <p>108: Why does the moon have phases?</p> <p>109: Do we only see one side of the moon?</p> <p>115: Does the moon move in same path every night?</p> <p>116: 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?</p>	<p>Group 4: Star investigations</p> <p>107^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.</p> <p>112: 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.</p> <p>114: 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.</p> <p>118: Is the "earth moving more than [the] stars?</p>

^aSome students did not write questions so their predictions are included here instead.

Note: Words placed in brackets were added or changed to improve the clarity of the student's writing.

Table 4 – Student inquiry projects – Focus questions for their investigations

Student Inquiry Projects

Students conducted their own inquiry investigations of the patterns of motion for celestial objects. Though students chose their own questions and topics, this was initially framed by the instructor through discussion of the sky, an observation of the moon, and the pre-assessment on the day the project was introduced. Within this framework, the students chose a broad range of questions to investigate; Table 4 gives the focus question(s) for each student, organized by the groups that they worked in. While each group was investigating the same celestial object (sun, moon or the stars) they had individual questions within that area. In some groups these questions

were complimentary (Does the position of the sun vary with the season over time? And, Does the position of the sun at noon change?) while in other groups the investigation questions were more diverse (Why does the moon have phases? And, Does the moon move in same path every night?). In class, the groups discussed their observations and their investigation plans. This work likely influenced how some of the investigations progressed by helping to focus the questions and observations as well as the observing techniques.

Post-instruction understanding of celestial motion concepts

We examined the change in students’ understanding of the concepts covered in the assessment to uncover how the students’ diverse investigation experiences changed their overall understanding of apparent and actual celestial motion. Table 5 shows the number of students 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 the description of the sun’s path in summer and winter (33% of students), apparent motion of the moon (56% of students), description of the stars’ apparent motion (67%) and explanation for why the stars appear to move (56%). Some areas showed very little improvement: seasonal change, explanation of the sun’s apparent motion, and explanation of the moon’s apparent motion. To clarify lack of improvement in the seasonal change of the sun’s path, as shown in Table 5, almost as many students regressed (27%) as improved (33%) their descriptions of this change. This suggests a number of possibilities: the students’ understanding is not well developed and the changes they drew in the assessment were not in fact meaningful to them, some students’ investigations led them to wrong conclusions about the sun’s apparent motion (which appears to be the case for at least S101), or the way that we coded the students’ drawings did not pick up on subtle changes that were significant to the students in showing differences. Most students (67%) did not improve their explanation of why the sun appears to move; however, 10 of these 12 students already had the full scientific understanding before instruction began. This does suggest though that because five students did not give the scientific explanation at the end of this investigation that this topic should be given more instructional time within any introductory inquiry astronomy project.

	Improved	Regressed	No change
Path of the sun in summer	6	1	11
Path of the sun in winter	6	2	10
Comparison of the sun’s path across the seasons	6	5	7
Path of the moon	10	1	7
Apparent motion of the stars	12	2	4
Explanation of the sun’s motion	4	2	12
Explanation of the moon’s motion	2	4	10
Explanation of the stars’ motion	10	0	8

Table 5 – Impact of inquiry investigation on students’ descriptions (N=18)

The explanation of the moon’s apparent motion remained an area that few students understood after this investigation. After the investigation only four students explained that the moon appears to move across the sky because of the earth’s rotation and two of these students gave that explanation before the investigation. Observations of the moon and work with models did not

improve their understanding of the connection between observed motion and actual motion. To put this in perspective, 13 students described the moon’s apparent as a smooth curve across the sky (12 equating this with the sun’s apparent motion). Yet only four of these students explained this apparent motion with the earth’s rotation (and only two of those students were investigating the moon; the others investigated the sun and the stars). The remaining students were more likely to use the Moon’s actual motion to explain the apparent changes. These results suggest that teaching students to explain why the moon appears to move will require a more targeted approach than was taken here.

Connection between investigations and change in understanding

We also analyzed across each student and compared their chosen area of inquiry to the ways that their understanding changed over the instructional period. Some of the students improved in the areas related to their inquiry questions as well as other topics outside of their inquiry investigation. The matrix in Table 6 lists the students in each condition found by crossing improvement in area of investigation with improvement in other conceptual areas. There is no correlation between the topic that the student chose to investigate (sun, moon or the stars) and where they fell on the improvement chart, nor did this correlate with the group that they were in.

	Improvement in conceptual area of investigation	No improvement in conceptual area of investigation
Improvement in areas not included in investigation	108, 109, 110, 111, 114, 115, 116, 118, 119	101, 104, 112 ^a , 117 ^a
No improvement in areas not included in investigation	105, 107, 113	102, 103

^a Student began at full understanding of concepts under investigation

Table 6 – Relationships between areas of investigation and areas of improved understanding

To understand the relationship between the investigations, classroom instruction, and areas of improvement for these students we made a close examination of the students’ science journals and presentation posters. Twelve of the students (66.7%) showed improvement in areas that related to their area of investigation. Six students (33.3%) did not improve in their areas of investigation. However, two of those students may have already held the full understanding of their conceptual area (as measured by the assessment). S112 already held a full understanding of the concepts she investigated (motion of the stars) prior to beginning her investigation, at least to the level assessed in this study. Also, S117, who investigated concepts relating to the Moon, understood the scientific description of the moon’s apparent motion in the pre-assessment but regressed in understanding of why the moon appears to move. However this is because in her post instruction answer to why the moon appears to move, she gives the vague response: “It appears to move because the earth is moving” rather than specifically attributing its motion to the earth’s rotation. It is possible that the lack of improvement in this student’s understanding is also due to a ceiling effect in post-assessment.

S107 investigation of the apparent motion of the stars led to improvement of this conceptual area, but not other areas. Before her 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. Her initial prediction was that the stars would be in the same place each night at a given time and her investigation evolved into determining whether or not the constellations' positions would shift slowly over the course of months. S107's observations focused on tracking the position of Orion's belt, as well as the time, temperature, and position of the moon if visible. She improved her ability to describe the stars' apparent motion and used the earth's rotation to explain that motion. She also improved her understanding of the change in the sun's path over the seasons and used the earth's rotation to explain why sun appears to move. Her inquiry did not lead to improved description of the path of the moon or to explaining the moon's motion with the rotation of the earth. Her inquiry project improved her understanding but not to a full picture of earth's impact on celestial motion.

Other students' inquiry investigations led to improvement in areas outside of their investigation but not within the conceptual area of their investigation. S101 investigated the question "Does the sun change position when observed day to day at the same time from the same observer point?" Before her investigation, she described the sun's apparent motion in summer as a straight line through the zenith from east to west. S101 also described the sun's path in winter as a straight line across the sky, but just barely south of east and south of west, and slightly below the zenith, though this was not a significant enough difference to be counted as an accurate description of the change in the sun's path over the seasons. She also did not believe that the moon or stars appear to move, though she did explain the sun's apparent motion with the earth's rotation. After her investigation, the path she drew for the sun summer was not accurate – a smooth curve rising north of east but setting south of west. Her path for the sun in winter was opposite and therefore crossed the sun's summer path. She had learned through her investigation that in the summer the sun rises north of east, but had not accurately extended this to the afternoon position (because this was not included in her observations). However, she improved in her descriptions of the apparent motion of the moon and the stars, and used the earth's rotation to explain these motions. It is likely that she improved in these ways due to discussions in class and presentations from other students also investigating those concepts.

Discussion

Students' difficulty with learning to describe and explain celestial motion may impact their ability to learn and teach more advanced topics such as phases of the moon and the seasons. As has been shown with previous studies, many pre-service and in-service teachers do not accurately explain concepts that are considered appropriate for elementary students to learn (Atwood & Atwood, 1995; Mant & Summers, 1993; Parker & Heywood, 1998; Trundle, Atwood, & Christopher, 2002). This study has shown that teachers do not hold scientific understandings of the patterns of apparent motion of the sun, moon and stars. We have also shown that even students who could use the rotation of the earth to explain the sun's daily motion did not use this to explain the apparent rising and setting of the moon and stars.

The results of this study demonstrate the difficulty pre-service teachers face in learning to describe and explain celestial motion. Even though most students began with an accurate

explanation for the sun's daily motion, there was an insignificant improvement in the number of students who used the earth's rotation to explain the day/night cycle after their investigation. The improvement in the area of the stars' apparent motion and the explanation for that motion was surprising. Most students who improved in this area were not specifically investigating this topic. A combination of factors may have led to this improvement. Observing the moon at night may have included thinking about the stars. The whole class observed a demonstration of why we see a seasonal change in the stars visible at night. The group investigating the stars gave two presentations with clear descriptions and explanations of the concepts. However, the fact that the majority of the students completed their investigations without accurately explaining the moon's motion suggests that a different approach is needed. These results also suggest that more focused instruction is required for students to understand and take up the use of the earth's rotation to explain their observations and to extend this explanation to its full use across the motion of different celestial objects. 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. Translating observations of the sun's position in the sky to a 3-D representation may require additional scaffolding beyond what was provided in this study.

This study was set in a science methods classroom where students were encouraged to pursue their own lines of inquiry on topics of observational astronomy as a model for improving inquiry as described in the National Science Education Standards (NRC, 1996). The promise of this study is that most students (89%) did improve in their understanding of some aspects of celestial motion, with two-thirds improving in their area of investigation. This study investigated the use a very open inquiry investigation; little classroom time was spent guiding the investigations or providing explanations for their observations. Analysis of the journals showed that students were learning concepts beyond what was measured in the pre/post assessments. This included developing observational techniques to aid in their observing projects and finding additional resources on the internet.

Our analysis of students' participation in this inquiry project suggests some ways of improving future curriculum design and classroom instruction. Some concepts will require more purposeful instructional intervention than this open inquiry experience could provide. Observations of the moon and prompts to explain observations did not lead to students' changing their initial ideas about why the moon rises and sets to the scientific explanation of the earth's rotation even when they used the earth's rotation to explain other apparent motions. Further care should be used to guide the choice of questions to investigate to better match investigation topics towards conceptual development in celestial motion. Students will also require additional guidance in connecting the patterns of motion as a coherent whole when they only focus on one aspect of celestial motion. The results of this study may help us design educative curriculum for teachers who are likely to hold the same level of understanding of astronomy as their elementary students (Davis & Krajcik, 2005). Materials should provide clear examples of what teachers' may expect to find in observational projects, explanations of how to model these phenomena, suggestions for how to help make connections across each conceptual area, and descriptions of how this differs from common misconceptions. Our results also suggest may help curriculum developers understand which topics will be less successful in helping students learn these concepts (such as understanding whether or not the moon rotates or understanding the phases of the moon).

Future research

Future studies are needed to investigate how such an open inquiry experience can be completed while students also experience additional opportunities to improve their understanding of the patterns of motion and how to explain those motions in more structured classroom formats. It may be that a combination of open inquiry investigations and more structured in-class modeling of the whole sun-earth-moon system to explain apparent motions will be necessary to improve teachers' overall understanding of these concepts. However, such an approach is likely to increase the amount of classroom time spent on these topics which limits the likelihood that such an approach will often be used. And if the focus shifts from a more guided inquiry approach, we may wonder if we are limiting some of what students may come to understand about the nature of science and astronomical research. This also prompts us to wonder how the use of this open inquiry environment in astronomy affected the students' thoughts on teaching astronomy via inquiry, as this was not assessed as part of this study.

Additional research is needed to further clarify how we can we effectively design instruction that uses students' own inquiry through observations of celestial objects and provides additional guidance needed to improve understanding, in the limited time we have to teach these concepts. Recent work using computer astronomy programs (Hobson & Trundle, 2007) and the planetarium (Plummer, 2007) suggests the use of technology may be the answer. In the original instructional plan for this study, we considered having the students plan and implement a brief lesson on the concepts that they were investigating. We wonder how including would have changed the students' understanding of these concepts. And given that it is unlikely that most teachers will have similar opportunities in undergraduate astronomy courses or science methods courses, can we design educative curriculum 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 and the impact of such a curriculum on the teachers and the students' change in understanding.

Conclusion

Pre-service elementary science teachers do not hold a scientific understanding of elementary concepts of celestial motion: the daily patterns of motion of the sun, moon and stars and that the earth's rotation explains all of these motions. Most students appear to be aware of the earth's rotation or conflate their explanations with knowledge of the orbit of the earth or orbit of the moon. While students' open inquiry experiences were often successful in improving their descriptions of celestial motion in their area of investigation and some additional areas as well, the students did not reach a full understanding of celestial motion. Focused observational experience is not enough; additional dedicated time is required to further improve students' understanding towards the scientific explanation.

Appendix 1: Celestial Motion Survey
Celestial motion survey questions

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.
 - a. 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.
 - b. Explain why you would see that motion of the sun.
2. Imagine it is now the first day of winter.
 - a. 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.
 - b. 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.
 - a. Does the moon appear to move? If so, draw this path on the dome in GREEN.
 - b. 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.
 - c. 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: Celestial Motion Codes
APPARENT CELESTIAL MOTION

Sun’s path in summer

Spath: Is the sun’s path a smooth arc in the summer?

Accurate, non-normative, unclear

Szen: Does the sun pass below the zenith at its highest point of its path in the summer?

Accurate: below the zenith (any path that stays below 90 degrees from the horizon, north or south)

Non-normative: through the zenith or less than 15 degrees from the zenith (thus not clearly separating the line from where the zenith would be)

Shor: Does the sun rise north of east and set north of west in the summer?

Accurate: Yes must be at least 15 degrees from due East and due West

Non-normative: Any other combination of rise & set position

Sang: Is the sun's path at an angle towards the south in the summer?

Accurate, non-normative, unclear

Sun's path in winter

Wpath: same as Spath

Wzen: same as Spath

Whor: Does the sun rise south of east and set south of west in the winter?

Accurate: Yes – must be at least 15 degrees from due East and due West

Non-normative: Any other combination of rise & set position

Unclear/didn't answer – Includes "I don't know" for winter question

Wang: same as Sang

Comparing the sun's path across seasons

Calt: Is the sun higher in summer compared to winter?

Accurate – separation of paths must be at least 15 degrees.

Non-normative, unclear

Chor: Does the sun's rising and setting positions shift towards the south from summer to winter?

Accurate: Yes – shift must be at least 15 degrees and the shift must be towards the south

Partially accurate: Rising and/or setting positions shift (shift of at least 15 degrees) but not accurately presented

Non-normative: No change

Clen: Is the length of the sun's path longer in summer compared to winter?

Accurate – Summer path must be at least 30 degrees higher than the winter path. Partially

accurate – Summer path is between 30 higher and 15 degrees higher than the winter path.

Non-normative – includes paths that are within 15 degrees of each other.

Path of the moon

Mmv: Does the moon appear to move?

Accurate: Yes, but does not need to describe the motion

Non-normative: No

Mpath: Is the moon's path a smooth arc across the sky?

Accurate

Non-normative – Include students who say that the moon moves but do not draw it

Msun: Does the moon follow the same type of path as the sun?

Accurate: Same direction, same overall appearance and angle of path as the sun. Can be across the northern or southern side of the sky.

Non-normative – Include students who say that the moon moves but do not draw it.

Mphases: How long does it take for a full cycle of phases of the moon?

Accurate: 28 days, 29 days or approximate a month or a month or 27 days

Non-normative: anything else

Motion of the stars

Stmv: Do the stars appear to move?

Accurate: Yes (but not necessarily accurately described)

Non-normative: No, including “I don’t know.”

Stpath: Do the stars appear to follow the same path of motion as the sun, i.e. a smooth path from east to west?

Accurate: Includes **both** a smooth curve for the path of a star on their hemisphere and indicates that the stars move like the sun on their written assessment

Partially accurate: Includes **either** an accurate answer on the hemisphere or the written assessment

Non-normative – include “I don’t know” and does not appear to move

Stdif: Do we see different stars throughout the night?

Accurate: Yes

Non-normative: No, or yes with an incorrect explanation or “I don’t know”

EXPLANATIONS FOR CELESTIAL MOTION

Sun

ExS: Does the student use the rotation of the earth to explain why the sun appears to move across the sky?

Accurate:

ExS-1: Accurate use of the rotation of the earth

Partially accurate:

ExS-2: The sun rises.

ExS-2b: Inaccurate use of rotation.

Non-normative:

ExS-3: The **sun** moves around the **earth**.

ExS-4: The earth moves or revolves around the sun to bring the sun.

ExS-5: The earth revolves around the sun and rotates.

Moon

ExM: Does the student use the rotation of the earth to explain why the moon appears to move across the sky?

Accurate:

ExM-1: The rotation of the earth

Partially Accurate:

ExM-1b: The Earth moves but does not specify rotation.

Non-normative:

ExM-2: The moon's actual motion makes it appear to move

ExM-3: The moon does not appear to move (so any explanation is inaccurate).

ExM-4: Student says "I don't know" or "Not sure"

Stars

ExSt: Does the student use the rotation of the earth to explain why the stars appear to move across the sky?

Accurate:

ExSt-1: The rotation of the earth

Partially accurate:

ExSt-2: Student uses the earth's orbit around the sun to explain why we see different stars at different times of the year.

ExSt-2b: Student uses earth's motion but it is not clear what motion is being described.

Non-normative:

ExSt-3: The stars do not appear to move.

ExSt-4: Does not know if stars appear to move.

Unknown/Unclear

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