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## RESEARCH REPORT

# A Cross-age Study of Children's Knowledge of Apparent Celestial Motion

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The US National Science Education Standards and the Benchmarks for Science Literacy recommend that students understand the apparent patterns of motion of the Sun, Moon, and stars by the end of early elementary school, yet no research has specifically examined these concepts from an Earth-based perspective with this age group. This study examines children's understanding of the patterns of apparent celestial motion among first-grade, third-grade, and eighth-grade students, and investigates the extent to which these concepts develop from elementary to middle school in students without targeted instruction. Twenty students at each grade level (total $n$ = 60) were interviewed using a novel interview setting: a small dome representing the sky, which allowed students to demonstrate their ideas. Analysis reveals that elementary and middle school students hold a variety of non-scientific ideas about all aspects of apparent celestial motion. While the eighth-grade students' understanding of the apparent motion of the Sun shows a greater level of accuracy compared with the third-grade students, across the majority of topics of apparent celestial motion, the overall level of accuracy shows little change from third grade to eighth grade. Just as prior research has demonstrated the need for instruction to improve children's understanding of the nature of celestial objects and their actual motions, these results support the need for research on instructional strategies that improve students' understanding of celestial motion as seen from their own perspective.

## Introduction

The focus of this study was to examine children's understanding of the apparent motion of the Sun, Moon, and stars, as seen from their perspective. The patterns of motion of the celestial objects, exhibited on a daily, monthly, and yearly basis, are among the most fundamental aspects of astronomy. It was observations of these motions that began the field of astronomy in early civilisations. The importance of

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learning these patterns is acknowledged by including them as learning goals for science literacy at the early elementary level in such documents as the US National Science Education Standards (NSES) (National Research Council [NRC], 1996) and the Benchmarks for Science Literacy (Benchmarks) (American Association for the Advancement of Science [AAAS], 1993). Drawing from the descriptions in these documents, children are expected to learn the following concepts of apparent celestial motion:

The Sun, Moon, and stars have patterns of movement as observed from the surface of the Earth:

1. The Sun, Moon and stars all appear to move slowly across the sky.
2. The Sun appears to move across the sky in the same way every day.
3. The path of the Sun changes slowly over the seasons.
4. The Moon moves across the sky on a daily basis much like the Sun.
5. The observable shape of the Moon changes slowly over about four weeks; the change is very slight over one day.

All of these motions are the result of the Earth's daily rotation on its axis in combination with the Earth's orbit around the Sun on its tilted axis and the Moon's orbit around the Earth over the course of about 28 days (see Franknoi, Morrison, & Wolff, 1997, for further information on this topic). At latitudes north of the Tropic of Cancer, as was the case for this study, the Sun never passes directly through the zenith. The seasonal change in the Sun's path results in a gradual shift in the rising and setting positions from the northern part of the sky in summer to the southern in winter. The Sun's altitude at noon also shifts from a point high above the southern horizon in summer to a much lower southern altitude in the winter. At latitudes north of the equator, the Sun's path is always at an angle towards the south (not straight up and down). Overall, the Sun's path in the summer is longer than in winter, resulting in a decrease in the length of day from summer to winter. The angle and appearance of the Moon's path is the same as the Sun's smooth path across the sky. The timing of the rising and setting of the Moon is determined by where it is in its orbit around the Earth, which also correlates with the rising and setting position and altitude of the Moon. The stars have paths across the sky as well. A star's path across the sky is always the same but the time that it rises and sets changes slowly as the Earth orbits the Sun. For any specific latitude, some stars never rise or set; instead, these circumpolar stars continually appear to circle around the celestial pole, which is an extension of the Earth's polar axis out into space.

Even though the apparent motion of celestial objects was well understood by ancient peoples, it is likely that children in today's culture have not acquired an accurate understanding of these patterns due to the challenging nature of learning these concepts from first-hand observations. The first challenge is the length of time for these patterns of change to occur. The Sun, Moon and stars appear to move across the sky in a period measured in hours. The second challenge occurs in the effort required to notice and recall changes in position of these celestial objects. Finally, many of these changes are often occurring when most people, children and adults, are not outside observing the sky. These challenges suggest that most children, especially urban children, have not learned how to accurately describe apparent celestial motion. Development of such knowledge requires the opportunity for observation and guidance from more experienced observers.

One major benefit of learning about apparent celestial motion in elementary school is that students will have observational knowledge about the world that needs to be explained. The NSES recommend that students in Grades K–4 should be developing observational and descriptive skills around concepts of astronomy, to be used as a basis from which to explain the actual motions in the solar system (NRC, 1996). Most school instruction does not adequately help students understand the connections between the observed motions in the sky and the deduced motions of the Earth and Moon from a Sun-centred perspective (Nussbaum, 1986). It is unlikely that students will be able to fully understand both apparent and actual motion if the instruction primarily focuses on motion from a view-from-above or Sun-centred perspective; such a leap, from the actual motion of celestial objects (including the Earth) to the apparent motion from one's perspective, requires the learner to make a complete shift in frames of reference while at the same time computing changes in motion. Even if students possess those reference-frame-shifting skills, they may lack the necessary depth of knowledge from which to build more abstract concepts. Flavell, Miller, and Miller argue that, for children, 'expertise is particularly important because their more abstract knowledge allows them to generate causal explanations about that domain. These causal explanations in turn constrain the inferences they generate about novel instances' (1993, p. 144). Thus children may be unable to reason between frames of reference due to their lack of knowledge of the nature of the objects involved and the observable properties pertaining to the subject, not simply their developmental level. This lack of knowledge may include a full understanding of the shape of the Earth and their location on that Earth, how the curvature of the Earth may affect their observations, the distance and nature of the stars, and the difference between the orbits of the Moon and Earth and the rotation of the Earth.

Extensive research on children's cosmologies (primarily examining their understanding of the Earth, Sun, Moon, and stars as astronomical objects) has found that young children have constructed alternative frameworks that they use to interpret their world. Several studies have found that children do not see the Earth as a cosmological object, spherical in nature, with gravity pulling objects to its centre (Agan & Sneider, 2004; Bryce & Blown, 2006; Klein, 1982; Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Ohadi, 1998; Sneider & Pulos, 1983; Vosniadou & Brewer, 1992). Children's understanding of the Earth, Sun, Moon, and stars develops through their own observations of the world and through cultural mediation, such as the cosmology of their culture (Bryce & Blown, 2006; Diakidoy, Vosniadou, & Hawks, 1997; Klein, 1982; Samarapungavan, Vosniadou, & Brewer, 1996; Siegal, Butterworth, & Newcombe, 2004) or their knowledge of geography (Siegal et al., 2004). Seminal work in this area was performed by Nussbaum and Novak (1976), where they found a progression of mental models of the Earth's shape and gravity held by elementary children. These models ranged from a flat Earth with a sky above and a belief that there is a universal down direction of gravity, to the fully scientific understanding of a spherical Earth where gravity pulls to the centre; in between these conceptions range synthetic models that combine aspects of the observable world and naïve physics with the scientific models taught in school and through other cultural experiences (Vosniadou & Brewer, 1992).

Children's alternative frameworks also include their understanding of the Sun, Moon, and stars, how and why these objects move, and how they cause familiar phenomena such as the day–night cycle and phases of the Moon. Children's explanations for the day–night cycle cover range of possible non-scientific mechanisms, including clouds occluding the Sun, the motion of the Sun (moving out into space, up and down on the ground, going to the other side of the Earth or going around the Earth), and that the Earth moves around the Sun (Baxter, 1989; Vosniadou & Brewer, 1994). These studies suggest that while elementary-aged children know that the Sun is involved in the switch from day to night, some may not be familiar with the apparent motion across the sky. Children also lack an appreciation for the size of the Sun compared with the Earth, which may impact their choice for the active body (Klein, 1982). Children's explanations for the motion of the Moon also suggest that many children have a limited understanding of the apparent motion of the Moon. Vosniadou and Brewer (1994) found that children do not accurately combine the apparent motion of the Moon due to the Earth's rotation with the actual orbit of the Moon around the Earth, leading some students to believe that the Moon does not move while others state that it appears to move in some unspecified way. Some children believe that the Moon is in some way responsible or necessary for night, tying its motion opposite to that of the Sun. Vosniadou and Brewer also found that children may believe that the stars go to some other location during the day and that children who believe that the stars are still in the sky during the day also believe that the stars never move.

Studies of children's cosmologies help us understand how children view their world and the interaction of celestial objects, and demonstrate to us that children often believe that the apparent motion we see of the Sun, Moon, and stars is caused by the actual motion of these objects. However, most previous studies have not separated out how children may describe the patterns of apparent motion of the Sun, Moon, and stars, as one would see them in the sky, from how they may describe their ideas about these objects' actual motion. It was this relative lack of research on the apparent patterns of motion—despite prominence in national documents such as the NSES—that prompted Adams and Slater to recommend that, to improve astronomy education, 'the first task for the lower grades is to evaluate student geocentric conceptions of the day and night sky' (2000, p. 12). Therefore, this project has been designed to give a detailed analysis of early elementary and middle school students' knowledge of the patterns of apparent motion for the Sun, Moon, and stars from an Earth-based perspective in order to provide a basis for the development of instruction.

Two previous studies have examined these concepts among populations that are older than the ages recommended by the NSES and the Benchmarks: upper elementary students and teachers in England. Sharp (1996) interviewed 42 students in Year 6 (10 and 11 years old) about their knowledge of the Sun, Moon, and stars. The methodology of this study—interview questions answered with only gestures and drawings—limits the usefulness of the results in fully understanding the children's understanding of apparent celestial motion. The study found that 24% of the students were unaware of the apparent motion of the Sun, 64% did not know that the Moon appears to rise and set, and 86% were unaware of the apparent motion of the stars (the slow shift in the stars position caused by the rotation of the Earth). The second study investigated the astronomy knowledge of 20 primary school teachers in England (Mant & Summers, 1993). Mant and Summers' interview protocol involved the use of a three-dimensional model to represent a person standing on a small mountain, surrounded by a circular card representing the horizon. The teachers showed a better knowledge of the Sun's apparent motion; all knew that the Sun rises and sets, and 70% knew that the Sun's altitude is higher in summer than winter. However, only 10% knew that the Sun's rising and setting positions shift across the seasons, only 30% were able to articulate that the Moon appears to move, and only 20% could describe the motion of the stars.

The differences in these two groups' level of understanding could be attributed to the difference in age of the participants or to the two methodological approaches. Similarly, different methods used to explore children's understanding of the shape of the Earth have resulted in debate over the extent that physical models may influence a subject's response. Significant research has found that through upper elementary school, and even middle school, many children do not understand the Earth as a cosmic body, a spherical object unsupported in space (Agan & Sneider, 2004; Blown & Bryce, 2006; Nussbaum, 1979; Sneider & Pulos, 1983; Vosniadou & Brewer, 1992), even after targeted instruction (Hayes, Goodhew, Heit, & Gillan, 2003; Nussbaum & Novak, 1976; Nussbaum & Sharoni-Dagon, 1983; Sneider & Ohadi, 1998). However, additional studies performed using an Earth globe found that most children were able to correctly answer questions relating to the shape of the Earth and where we live through the use of this tool, as young as those in first and second grades (Schoultz, Säljö, & Wyndhamn, 2001). Similar results have been found with children interacting with a flat map of the world during interviews (Ivarsson, Schoultz, & Säljö, 2002). All participants, children aged seven–nine years, indicated that people cannot fall off the Earth. Using the map or globe to mediate reasoning, children did not exhibit any of the alternate conceptions about the shape of the Earth (the flat Earth, hollow Earth, etc.) as are seen when children do not have a scientific representation of the Earth. However, accurate use of such scientific models as the globe may still mask existing misconceptions about the Earth and gravity.

> Children reason on the basis of the externally provided artifact when this is unavoidable, but when the answer cannot be derived directly from the external model they rely on prior knowledge. The children do not seem to be aware of this process that somehow distorts their rationality producing internal inconsistency. (Vosniadou, Skopeliti, & Ikospentaki, 2005, p. 350)

Vosniadou and colleagues also investigated children's use of cultural artefacts. Their results suggest that children can use such an artefact to answer questions that can be 'read' directly from the object, but have far more difficulty with making inferences that generate new knowledge. In these situations, children will revert back to their prior knowledge and alternative mental models. These studies suggest that while tools can be an asset in facilitating students' ability to explain their thinking, there is still debate as to the conclusions we can draw from studies that use tools versus those that do not.

## Research Questions

The purpose of this study was to uncover and describe students' knowledge of the patterns of apparent motion of the sun, Moon, and stars, as seen in the sky from their perspective, across elementary and middle school. Students from the first and third grades were chosen because these grade levels bracket the early elementary age level—the level at which the NSES and the Benchmarks recommend children study these concepts. Eighth-grade students were chosen in order to examine whether or not children's ideas change significantly by the end of middle school. Many students do not receive additional instruction on astronomy concepts after middle school in the USA. Previous studies have described how children view these celestial objects, their relationship to the Earth, and how they explain astronomical phenomenon. The present study extends our understanding of children's astronomical knowledge by exploring how children describe the appearance of motion in the sky from their own perspective. The students did not receive any special instruction on these concepts. The answers to these questions may help curriculum developers improve children's observational knowledge through constructivist instruction that considers children's alternative descriptions of apparent celestial motion:

1. What are students' conceptions of the patterns of motion of the Sun, Moon, and stars, as viewed from the Earth?
2. How do students' conceptions of the motion of the Sun, Moon, and stars compare among first-grade, third-grade, and eighth-grade students?

## Methodology

### *Participants*

A total of 60 students from the first, third, and eighth grades were interviewed for this study. Students had not previously studied astronomy during the school year in which they were interviewed. Ten girls and 10 boys were randomly selected from each grade level (except for the first grade; only eight boys had signed permission letters, so an additional two girls were also interviewed). The mean age of the first-grade students was 6.6 years ($SD$ = 0.3). The mean age of the third-grade students was 8.7 years ($SD$ = 0.3). The mean age of the eighth-grade students was 13.8 years ($SD$ = 0.4).

The first-grade and third-grade students attended the same public elementary school in a small town in Midwestern USA. The student body of this school is 96% Caucasian, 1% Native American, with other ethnicities forming the remaining 3%. Eighteen percent of students at the school are eligible for free or reduced-price lunch.

The eighth-grade students attended a public middle school in another small Midwestern USA town. The student body of this school is 97% Caucasian, 2% Hispanic, with the remaining 1% from other ethnicities. Twenty-eight percent of the students are eligible for free or reduced-price lunch.

Both of these schools are at 42° north latitude (this determines the details of the apparent paths of celestial bodies).

### *Interview Setting and Protocol*

The topics covered in the interview were selected primarily based on the astronomy concepts found in the NSES (NRC, 1996) and the Benchmarks (AAAS, 1993) for early elementary grades. A description of the 16 categories and representative interview questions are presented in Tables 1–5 (the categories and codes listed in Table 1 were used for both the Sun in summer and in winter). Additional questions were used to help the students imagine they were outside during the summer, winter, or at night, and to clarify responses to the interview questions.

Table 1. Codes developed for the apparent motion of the Sun in summer and winter

| Category | Codes |
|---|---|
| **Path**: How does the student describe the path of the Sun in summer/winter?<br>*Representative questions:*<br>• Where is the Sun first thing in the morning?<br>• Where is the Sun at 10 o'clock?<br>• Where is the Sun at noon or lunchtime?<br>• Where is the Sun in the afternoon when school gets out?<br>• What happens to the Sun at the end of the day? | **Path-1: The Sun's path is a smooth curve that does not pass through the zenith. The sun rises and sets on opposite sides of the sky. This means that there must be more than 45 degrees between where the sun rises and where it sets, as measured in azimuth (along the horizon).<br>Path-2: The student demonstrates the same path as described in the accurate code except the sun passes through the zenith.<br>Path-3: The path of the Sun includes rising and setting and does not pass through the zenith but also includes other inaccuracies.<br>Path-4: The path of the sun includes rising and setting but also has a sharp turn of more than 45 degrees within the path. The path is not a smooth curve.<br>Path-5: The motion that the student demonstrates does not resemble the actual path of the Sun. Examples include: the student may show the sun circling around the zenith or the path may cross the sky in multiple directions throughout the day.<br>Path-6: The student demonstrates that the rising position of the Sun is less than 45 degrees (in azimuth) from the setting position (the motion generally appears to move straight up and then straight down).<br>Path-7: The student shows more than one path of the sun during the interview. |

Table 1. *(Continued)*

| Category | Codes |
|---|---|
| • Show me again what the Sun does throughout the entire day.<br>*Coding* was based on students' visual demonstration in response to the questions above. | |
| **Zen**: Is the Sun below the zenith at its highest point?<br>*Representative questions:*<br>• Where is the Sun when it is highest in the sky?<br>• Is that directly overhead?<br>*Coding* was based on both the students' visual demonstration of the Sun's path (twice) and their verbal response the above questions. | **Zen-1: When the student demonstrates the path of the Sun it does not pass through the zenith. The student also points below the zenith when asked where the Sun is when it is highest in the sky AND when asked if that point is directly overhead the student responses with a negative.<br>Zen-2: The student gives an inconsistent answer. The student's verbal response and visual demonstration do not agree.<br>Zen-3: The Sun passes through the zenith when it is highest in the sky and the student says this is directly overhead. |
| **Noon**: Is the Sun highest at noon?<br>*Coding* was based on comparison of when the student says that the Sun is highest and their visual demonstration of this position. | **Noon-1: The student visually demonstrates that the Sun at its highest point at noon.<br>Noon-2: The student says that the Sun is highest at noon, but also visually demonstrates that the Sun is highest at some other time of day.<br>Noon-3 The student indicates that the Sun is highest at some other time of day.<br>Noon-4: The Sun remains at the same altitude throughout part of the day, including noon. For example, the Sun main remain at the zenith for most of the day before setting.<br>Noon-5: Student says s/he does not know when the Sun is highest |
| **Con**: Is the Sun's motion continuous?<br>*Coding* was based on how students demonstrated and verbally described the path of the Sun. This was not explicitly asked. | **Con-1: The student demonstrates that the Sun moves continuously throughout the day and does not stop in any one position for an extended period of time.<br>Con-2: The student shows the Sun remaining in the same position for an extended period of time. For example, some students showed the sun rising up to the zenith in the morning, remaining there until the end of the day, and then setting. |

*Note*: The accurate response is indicated by **.

Table 2. Codes developed for the comparison of the Sun's path in summer and winter

| Category | Codes |
|---|---|
| **Cdir**: Is the direction of the Sun's motion the same in summer and winter?<br>*Coding* was based on the students' demonstration of the path in summer versus winter. The directions were indicated on the rim of the dome but these directions were not specifically noted by the interviewer and students were not specifically asked about directions. | **Cdir-1: The Sun's motion is in the same direction across the sky in summer and winter.<br>Cdir-2: The Sun's motion across the sky is in the opposite direction in summer compared to winter.<br>Cdir-3: The Sun's motion across the sky is shifted by more than 45 degrees (but is not exactly opposite) in summer compared to winter.<br>Cdir-4: The paths that the student described for summer and winter are not directionally comparable. This occurred for paths where the student did not show the Sun rising and setting on opposite sides of the sky. |
| **Clen**: Is the length of the Sun's path shorter in the winter compared to the summer?<br>*Coding* was based on a comparison of the distance between the rise and set positions, measured in degrees of azimuth, from summer to winter. Only differences greater than 45 degrees were counted as intentional. This somewhat arbitrary cut-off was chosen to ensure students were not coded as accurate for small shifts in where they indicated the Sun's rise or set position. The actual difference for students at this latitude is 135 degrees in azimuth. | **Clen-1: The student accurately demonstrated that the path of the Sun in winter is shorter than the path of the Sun in summer.<br>Clen-2: There is no significant difference in the length of the Sun's path across the sky. This includes paths were the Sun rises in the same location in summer and winter as well as sets in the same location on the opposite side of the sky in summer and winter. It also includes paths that are the same length but the rise and set positions are shifted when comparing the seasons.<br>Clen-3: The path of the Sun is significantly longer in winter than in summer.<br>Clen-4: The path of the Sun in summer is not comparable in length to the path in winter. This occurred for non-normative paths where the Sun did not cross the sky, such as rising and setting in the same place, or circling around the sky. |
| **Calt**: Is the Sun's altitude lower in winter compared to summer?<br>*Representative questions:* | **Calt-1: The Sun's altitude is lower in winter compared to summer. For the difference in altitude to be counted the student needed to both demonstrate the difference and indicate this verbally.<br>Calt-2: The student says that the Sun's altitude is lower in the winter but does not demonstrate this accurately. |

Table 2. *(Continued)*

| Category | Codes |
|---|---|
| • (Summer) Where is the Sun when it is highest in the sky?<br>• (Winter) Where is the Sun when it is highest in the sky? Is that the same as the summer?<br><br>*Coding* was based on both the students' demonstration (pointing to the Sun at a lower position in winter than in summer) and response to above questions | Calt-3: The highest altitude is the same in summer and winter. The student indicates this idea both by pointing with the flashlight and by verbally confirming that they are in the same position.<br>Calt-4: The Sun reaches the same altitude in summer and winter, but at different times of day.<br>Calt-5: Student indicates that the Sun is higher in the winter than the summer.<br>Calt-6: The student did not give enough information in order to make a comparison. |

*Note*: The accurate response is indicated by **.



Table 3. Codes developed for the changing appearance of the Moon

| Category | Codes |
|---|---|
| **Mdif:** Does the Moon appear in the sky in different shapes?<br>*Representative questions:*<br>• Can you draw a picture of the Moon for me?<br>• Does the Moon ever look different than that?<br>*Coding* was based on student's drawings of the Moon and their response to the question 'Does the Moon ever look different than that in the sky?' | **Mdif-1: Drawings included at least two accurate drawings of Moon phases.<br>Mdif-2: Student was unable to draw more than one shape for the Moon or there were other inaccuracies in their drawings. |
| **Mapp**: Does the appearance of the Moon change on the order of days or up to a month?<br>*Representative questions:*<br>• How long does it take for the shape of the Moon to change?<br>• Does the shape of the Moon change during the course of one night?<br>*Coding* was based on students' verbal response to the questions. | **Mapp-1: The student says that it takes more than a day but less than a month for the shape of the Moon to appear to change.<br>Mapp-2: It takes less than a day for the appearance of the Moon to change.<br>Mapp-3: It takes over a month for the appearance of the Moon to change.<br>Mapp-4: The appearance of the Moon never changes.<br>Mapp-5: The student does not know. |
| **Mngt**: Does the shape of the Moon appear to change over the course of one night? | **Mngt-1: No, the shape does not change during the course of night or the change is too small to notice. |

Table 3. *(Continued)*

| Category | Codes |
|---|---|
| *Coding* was based on students' verbal response to the questions. | Mngt-2: Yes, the shape of the Moon changes visibly during the course of one night.<br>Mngt-3: Student previously indicated that the shape of the Moon never changes.<br>Mngt-4: The student does not know. |
| **Mday:** Is the Moon ever visible during the daytime?<br>*Coding* was based on students' verbal response to the questions. | **Mday-1: Yes, the Moon can sometimes be seen during the daytime.<br>Mday-2: The student answers 'No', pauses, and then changes the answer to 'sometimes.'<br>Mday-3: No, we can never see the Moon during the day. |

*Note*: The accurate response is indicated by **.



Table 4. Codes developed for the apparent motion of the Moon

| Category | Codes |
|---|---|
| **Mpath:** How does the student describe the path of the Moon?<br>*Representative questions:*<br>• Let's pretend that it's night-time now. Where might we see the Moon when it first gets dark out?<br>• Where do you think we might see the Moon at midnight?<br>• If we went out just before we saw the sun again, where will the Moon be?<br>• Can you show me again what the Moon does during the night?<br>*Coding* was based on the visual demonstration that students made in response to the above questions. | **Mpath-1: The Moon's path is a smooth curve that rises and sets on opposite sides of the sky. The Moon does not pass through the zenith.<br>Mapth-2: The Moon's path is a smooth curve that rises and sets on opposite sides of the sky and also passes through the zenith.<br>Mpath-3: The student demonstrates two different paths for the Moon. One of the paths is accurate or partially accurate.<br>Mpath-4: The student demonstrates a path that does not fit in any other code but the path includes rising and/or setting (this may include a sharp turn in the path).<br>Mpath-5: The path of the sun includes rising and setting but also has a sharp turn of more than 45 degrees within the path. The path is not a smooth curve.<br>Mpath-6: The Moon moves around the sky but does not rise or set. Most students who were assigned this code demonstrated the Moon circling around the sky.<br>Mpath-7: The Moon remains in one place in the sky and never moves.<br>Mpath-8: The Moon rises and sets but spends most of its time up at the zenith.<br>Mpath-9: The student is unable to demonstrate the motion of the Moon. |
| **Msun:** Does the student show the same path for the Moon as for the Sun? | **Msun-1: The paths shown for the Sun and the Moon are similar in overall shape and direction. |

Table 4. *(Continued)*

| Category | Codes |
|---|---|
| *Coding* was based on a visual comparison of the drawings of the paths demonstrated for the Sun in summer and the Moon. | Msun-2: The shape of the paths shown for the Sun and the Moon are very similar but the directions are skewed by more than 45 degrees.<br>Msun-3: The paths of the Sun and the Moon have some similar features. For example, the Moon's path is a smooth curve through the zenith and the Sun's path is a smooth curve that does not pass through the zenith.<br>Msun-4: The student shows more than one path for the Moon but one of these is similar to the path of the Sun.<br>Msun-5: The path of the Sun is not similar to the path of the Moon. |
| **Mcon:** Is the Moon's motion continuous?<br>*Coding* was based on how students demonstrated and verbally described the path of the Moon. This was not explicitly asked. | **Mcon-1: The Moon moves continuously. It does not remain in one place for extended periods of time.<br>Mcon-2: The Moon stays in one place for extended periods of time. For example, the Moon remains at the zenith throughout most of the night.<br>Mcon-3: The Moon stays in one place and never moves.<br>Mcon-4: The student's answer is unclear or inconsistent. |

*Note*: The accurate response is indicated by **.



This project used a new interview setting designed to support students in clearly demonstrating three-dimensional concepts without relying entirely on verbal responses or drawings. All portions of the interviews were conducted in a small dome used to represent the actual sky (see Figure 1). The 6 ft (1.8 m) high structure resembled a very small planetarium dome (4 ft [1.2 m] in diameter). The student used a flashlight to demonstrate their ideas about the apparent motion of the Sun, Moon, and stars on the interior ceiling of the dome. This allowed students to model their understanding of patterns of motion in the actual sky. For the Sun and Moon's motion, students were asked to use the flashlight to demonstrate the motion twice. This gave both the student and the interviewer an opportunity to confirm the nature of their answer. Students showed consistency in their responses. Only one or two students at each grade level demonstrated more than one type of path. It is possible that some of the children, especially among the first-grade students, found it difficult to use the flashlight to express their ideas because they were limited in their manual dexterity. Generally, during the interviews the children appeared to have little difficulty in using the flashlight.

The author of this study, who conducted the interviews, was not known to the students prior to the interview sessions. To help the student understand the purpose of the interview questions and imagine the dome as a model of the real sky, the interviewer first explained the purpose of the dome and the flashlight. The interviewer then asked the student to imagine that they were outside on the first day of summer looking at the sky and to describe some of the activities they like to do when outside

Table 5. Codes developed for the apparent motion of the stars

| Category | Codes |
|---|---|
| **Stmv:** How does the student describe the apparent motion of the stars?<br>*Representative questions:*<br>• Let's pretend that is a bright star up there, just after sunset. Where would we see that star at midnight?<br>• Do the stars appear to move?<br>*Coding* was based on the students' verbal response to the above questions and corresponding demonstrations. | **Stmv-1: The student indicates that the stars appear to move during the night and is able to demonstrate a star appearing to move. The student does not need to represent an accurate path for the stars or that the stars rise and set but the motion should be similar to a star moving smoothly across the sky.<br>Stmv-2: The student says that the stars appear to move but there are inaccuracies in the motion (such as the stars moving back and forth across the sky), the student does not demonstrate the motion s/he describes or the student indicates that the motion takes longer than just one night.<br>Stmv-3: The student gives conflicting answers, first indicating that the stars do not move but later indicating that they do move.<br>Stmv-4: The student indicates that the stars do not appear to move in the sky. The students may have also said that only special stars or shooting stars move.<br>Stmv-5: The student indicates that the stars only move at the end of night. The student may also say that the stars all go to the other side of the Earth or go to be with the Moon. |
| **Stdif:** Do we see different stars during the night?<br>*Representative question:*<br>• If we went outside just before sunrise would we see the same stars as we saw just after sunset?<br>*Coding* was based on the students' answers to the questions. | **Stdif-1: We see different stars throughout the night. The student explains this using either the rising and setting of stars or the rotation of the Earth.<br>Stdif-2: We see different stars through out the night but the student does not provide an accurate explanation.<br>Stdif-3: We see the same stars every night but different stars across the different seasons or in different places on the Earth.<br>Stdif-4: The student says that we see different stars throughout the night but gives a non-scientific explanation. The student does not think that the stars rise and set.<br>Stdif-5: We see the same stars all night long, every night.<br>Stdif-6: The student is unsure or confused. |

*Note*: The accurate response is indicated by **.



in the summer. The majority of the students appeared comfortable with being interviewed, and expressed curiosity about the process and interview setting. Students were assured that their answers would not be shared with their teachers or affect their grades. Interviews were conducted one-on-one by the author in the students' school but outside their normal classroom. The interviewer was careful to use

Figure 1. Side view of the interview dome. The student uses a flashlight to indicate the position of the Sun, Moon, or star

language that was accessible to the youngest students (e.g., students were asked whether the Sun is 'directly overhead' or rather than using the term 'zenith'). This same language was used for the oldest students, who were informed that the interview was originally written for younger students.

Audio of each interview was recorded. Visual information from the students' demonstrations using the flashlight was drawn by the interviewer on a two-dimensional template representing the dome. These detailed diagrams were made for each student's answers about the path of the Sun in summer and in winter, the path of the Moon, and the motion of the stars (see Figure 2).

*Data Analysis*

The analysis of the interviews focused both on how the students demonstrated the apparent motion of the Sun, Moon, and stars and their verbal descriptions of these motions. For each category, the most accurate answer is indicated using a double asterisk in Tables 1–5. Additional codes were created to represent possible alternative ideas held by students. This initial coding scheme was then clarified and consolidated through the coding process so that all students' ideas were captured in the final list of codes. A description of how each category was coded is also included in Tables 1–5.

Some specific aspects of celestial motion were not examined in this analysis. This was done in part because of the general nature of the expectations of the NSES and the Benchmarks for this conceptual area and that a detailed scientific response may not be expected without advanced study. Students' responses for the path of the Sun (in summer and winter) were coded based on whether the student was able to draw a smooth path from one side of the sky to the other without passing through the zenith without also examining the directions or angle of the path. The students' description of the change in length of the Sun's path was compared without specifically examining whether they correctly identified the change from northern to southern rising and setting positions. The students' knowledge of the appearance of the Moon's path was coded but the change in when the Moon rises and sets was not. Finally, the students' knowledge of the stars' smooth apparent motion across the sky and appearance of rising and setting was examined, but their knowledge of circumpolar motion was not.

The combination of diagrams and audio recordings were used to assign a code representing the concept expressed during the interview for each of the categories. Use of the diagrams for coding was based on overall features of the paths that students demonstrated; therefore, small errors in how the interviewer drew the path have a limited impact on the validity of the method. The author coded all subjects. An additional researcher coded a sample of 15% of the students' responses, split evenly across the three grades. Inter-rater agreement was calculated by computing the ratio of agreements to the total number of categories. There was an 86% agreement when comparing code by code. Inconsistencies were then discussed and resolved to improve coding reliability in the study.

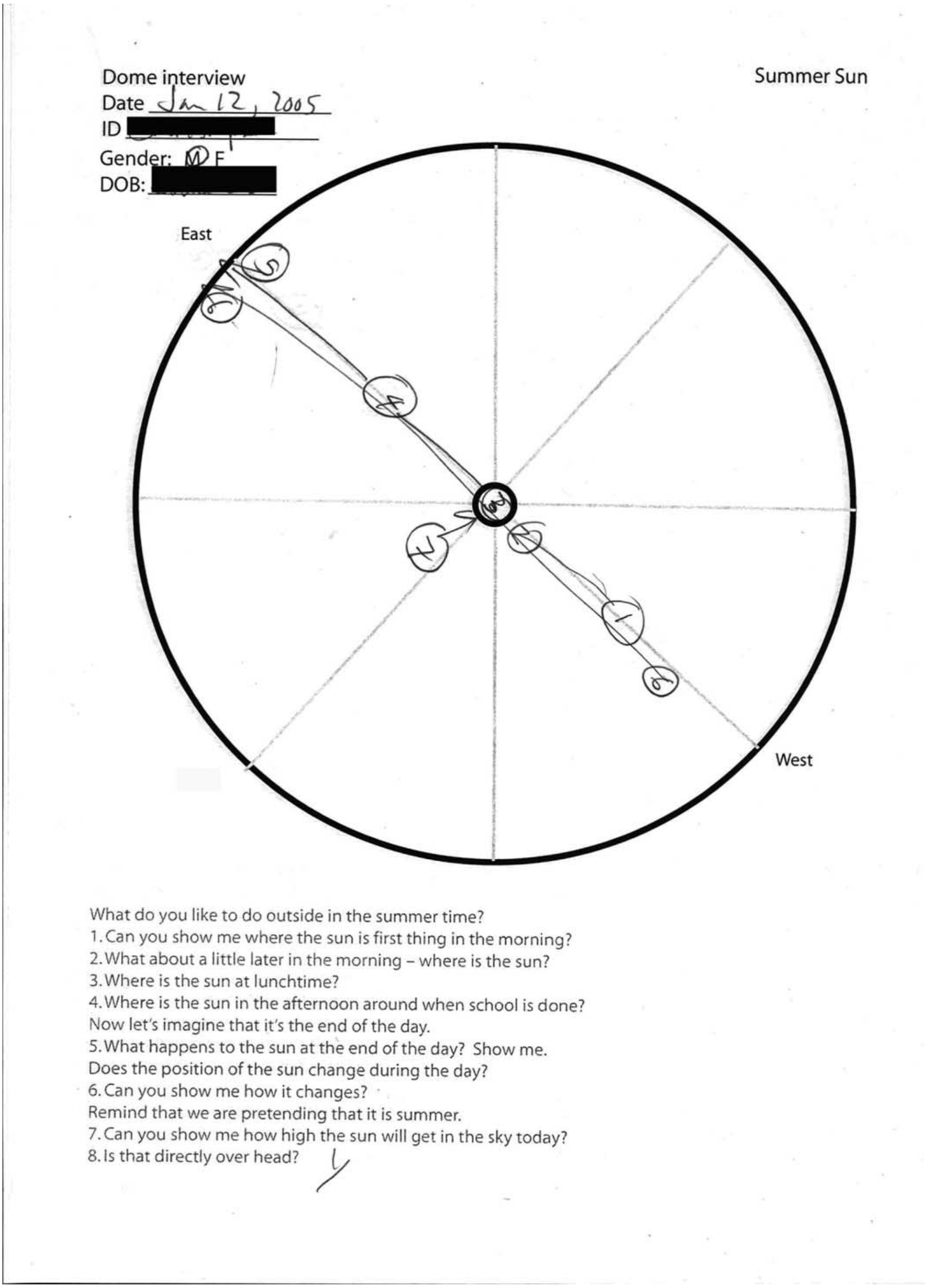


Figure 2. Example record sheet used during an interview for the Sun's motion in summer. Additional pages were used for questions about the Sun, Moon, and stars

## Findings

Throughout this section, the research questions are answered simultaneously: the description of students' ideas about each celestial motion category and the change between grade levels are presented.

### *Apparent Motion of the Sun in Summer*

First-grade students primarily demonstrated one of three different paths (none of which was the most accurate code): a smooth curve through the zenith (25%), a path where the Sun rose and set in approximately the same location (25%), or a path that included multiple inaccuracies compared with the actual path of the Sun (35%). The majority of third-grade students demonstrated the Sun's path as a smooth curve through the zenith (60%), but one-quarter of the students (25%) also believe that the Sun rises and sets in about the same location. Most eighth-grade students primarily demonstrated that the Sun's path is a straight path through the zenith (90%), with only one accurately demonstrating the path of the Sun below the zenith. This was a statistically significant shift across the grades towards the partially accurate path: a smooth curve across the sky passing through the zenith (Figure 3), $\chi^2(2, n = 60) = 17.42, p < .001$. The majority of students at each grade level believe that the Sun passes directly overhead in the summer. There was no significant difference in the number of students who held this belief between first-grade, third-grade, and eighth-grade students, $\chi^2(2, n = 60) = 0.66, p > .05$.

A large fraction of students (25%) in both the first and eighth grades was coded as 'inconsistent' in their understanding of the Sun's highest altitude. Perhaps some of the students have learned that the Sun is not directly overhead at its highest point but do not have the three-dimensional knowledge to accurately demonstrate this idea, or they did not believe that 'directly overhead' is the same thing as the middle of the sky. These results suggest that knowing that the Sun does not pass directly overhead does not necessarily correspond to a fully accurate three-dimensional understanding.

A large fraction (25%) of both the first-grade and third-grade students demonstrated that the Sun rises straight up to the zenith and then sets in nearly the same place. An additional two first-grade students initially demonstrated a path that did not fit any of the other regular patterns but later demonstrated this 'straight-up-and-down' description of the Sun's path. Students with this 'straight-up-and-down' belief about the Sun's motion have not yet had enough experience with the world to realise that the Sun rises and sets on opposite sides of the sky, or have not yet developed a sense of direction that would allow them to learn the correct description on their own.

The most frequent response for the first-grade students (35%) was a path dissimilar to the actual path of the Sun. These paths included the Sun beginning at the top of the sky and remaining their throughout the day, the Sun moving back and forth through the zenith or around the zenith, and one student unable to demonstrate any type of path. Perhaps for some of these students, a lack of dexterity or hand–eye

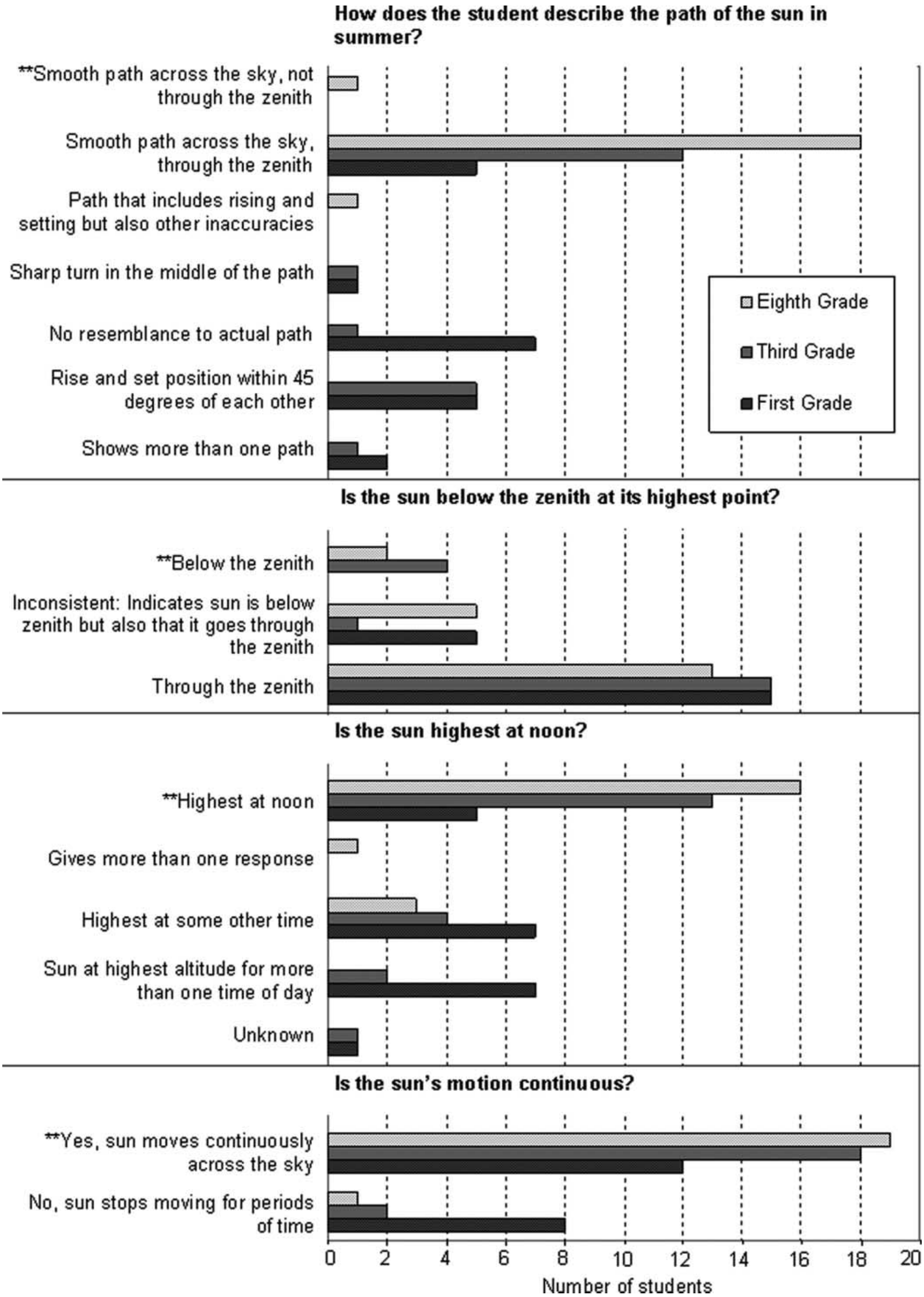


Figure 3. The apparent motion of the Sun in summer. Reading down the graph indicates the frequency (out of 20) of students holding that conception for each category, by grade level. The accurate response for each category is indicated by **

coordination could have contributed to this difficulty. However, some of their descriptions, such as describing the Sun's path as beginning at the top of the sky, seem to indicate that alternative conception about the world may be responsible.

Significantly more of the first-grade students indicated that the Sun's apparent motion is not continuous compared with the older students, $\chi^2(2, n = 60) = 9.57, p < .01$. Seven of the first-grade students, one third-grade student, and one eighth-grade student described the Sun as remaining at the zenith for all or part of the day. One additional third-grade student showed the Sun remaining at about 75° during the middle of the day. Another first-grade student who indicated that during the middle of the day the Sun is 'everywhere' was also coded as not showing continuous motion because she appeared to not understand the Sun's motion as a continuous path.

### *Apparent Motion of the Sun in Winter*

The number of students who demonstrated an accurate path for the Sun in winter increased slightly (two additional students in both the third and eighth grades), compared with the one student in the summer (see Figure 4). A larger portion of the first-grade students showed the 'straight-up-and-down' description of the Sun's path compared with summer, increasing from five students (25%) to 11 students (55%). The five students who demonstrated that path in summer demonstrated that same path in winter, while another five students had demonstrated a path with multiple inaccuracies.

More students accurately demonstrated that the Sun passes below the zenith in winter (20%) than in summer (10%). However, this difference is smaller if the students who inconsistently described the Sun's highest point are included (35% in winter compared with 28% summer). There is a more noticeable shift in the number of students at each grade who indicated that the Sun is highest at noon in winter compared with summer. More of the first-grade students indicate that the Sun is highest at noon in winter (45%) compared with summer (25%). The opposite pattern occurred among the older children. The percentage of students in the third and eighth grades who said that the Sun is highest at noon dropped in winter (40% in third grade, 60% in eighth grade) compared with summer (65% in third grade, 80% in eighth grade). This suggests that some students believe that the time that the Sun reaches its highest altitude depends on the season. The older students may be attempting to explain the change in the amount of daylight in winter compared with summer by shifting when the Sun appears highest. Or they may be attempting to explain the changing seasonal temperature or the fact that the Sun sets earlier in winter.

There was essentially no change in the number of students who indicated that the Sun's motion is not continuous and uniform in winter compared with summer. However, not all of the seven students in the first grade who indicated that the Sun does not move continuously during the summer also indicated this idea in winter. There were four students who only indicated the Sun does not move continuously in winter and four students who only indicated in summer. Thus, 55% of the first-grade students indicated in summer or winter that the Sun does not move continuously.

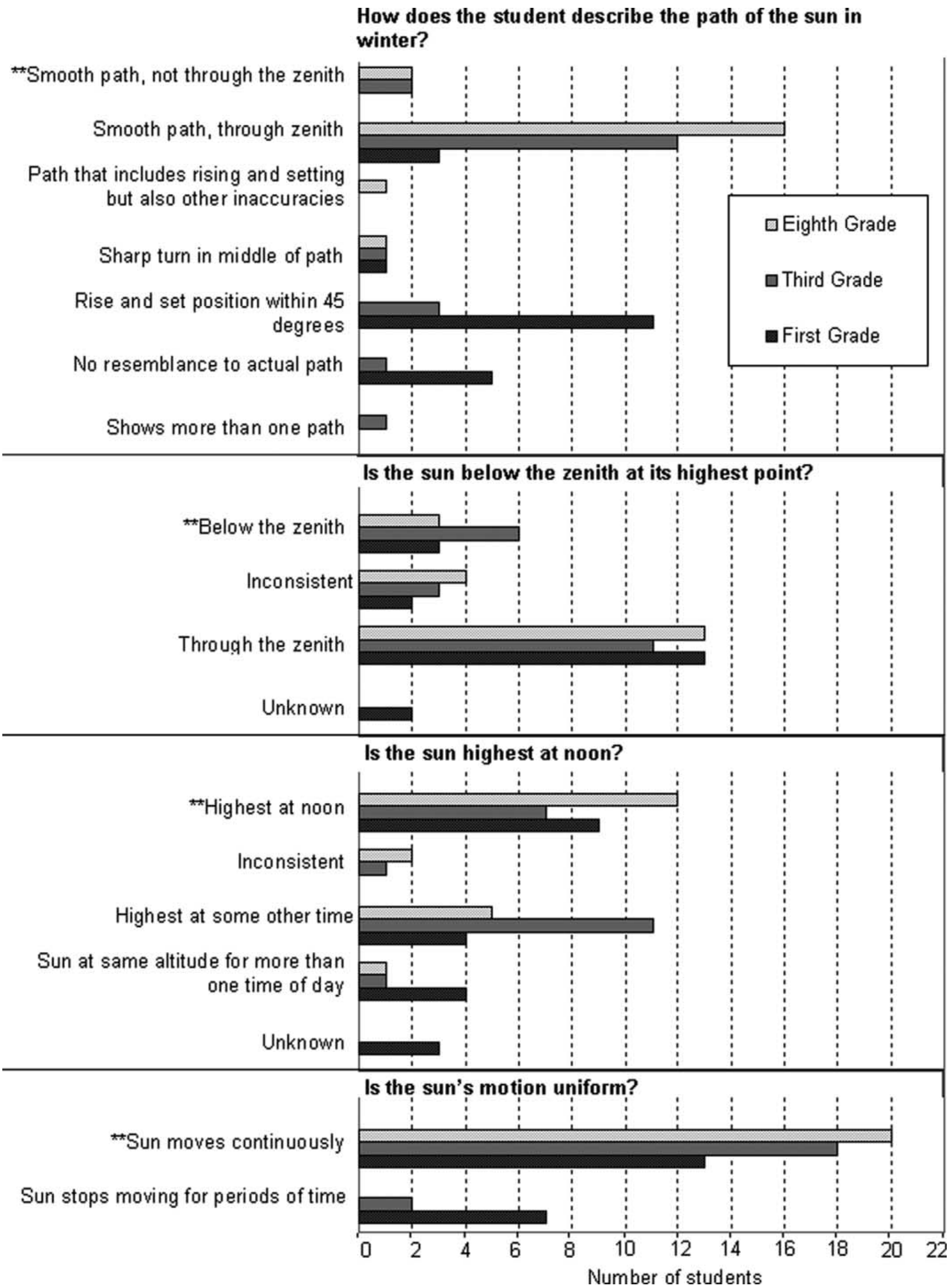


Figure 4. The apparent motion of the Sun in winter. Reading down the graph indicates the frequency (out of 20) of students holding that conception for each category, by grade level. The accurate response for each category is indicated by **

Similarly, an additional two third-grade students demonstrated that the Sun does not move continuously in winter (bringing the total number of third graders to three). These two third-grade students suggested that the Sun must move faster in winter in order for the days to be shorter. Lana compared why she showed a difference between summer and winter: 'Because in summer it's a longer day so it would be more up because it the Sun can't go too fast or the day would be shorter. But if the day was shorter here it could be going a little faster'. She also indicated that change in the speed of the Sun's motion is due to the Earth's motion. Nick also indicates a change in the Sun's apparent speed across the sky, but this change occurs across one day, not the seasons:

| | |
|---|---|
| Nick: | The days are shorter ⟨*⟩ it moves faster in the afternoon because it like in the morning it goes uhm quicker but like it goes in the afternoon it goes like it goes like it goes quicker. |
| Interviewer: | In the afternoon it goes quicker? |
| Nick: | It goes quicker than in the morning. |
| Interviewer: | So in the morning the sun is moving slower? |
| Nick: | Yeah, because afternoon it goes quicker because uhm it's moving faster because the orbits rotating faster because uhm because the days are shorter so it goes sooner in the afternoon. |

Both Lana and Nick indicate that they know the days are shorter in winter compared with summer and that the Sun follows the same path across the sky in summer and winter. Because they are unaware of the difference in the Sun's path length between summer and winter, they have explained the difference in a way that is consistent with their knowledge of the changing length of daylight and assumption about the nature of the Sun's path.

### *Seasonal Comparison of the Sun's Apparent Motion*

None of the students accurately demonstrated that the Sun's path is shorter in winter compared with summer. The majority of the students believe there is no difference in the Sun's highest altitude between summer and winter. Only two of the first-grade students, four of third-grade students, and two of eighth-grade students gave an accurate comparison both in their demonstration and verbal description. However, of those students, only the two eighth-grade students and one of the third-grade students also demonstrated an accurate path for the Sun, with the remaining five students including inaccuracies in their paths (Figure 5).

### *Appearance of the Moon*

The vast majority of students were able to draw, with some level of accuracy, at least two phases of the Moon (see Figure 6). Surprisingly, there were two eighth-grade students who did not draw or describe the phases of the Moon, even after probing questions. All of the third-grade students were able to draw at least two accurate phases of the Moon, but five of the first-grade students had inaccuracies. Two of the

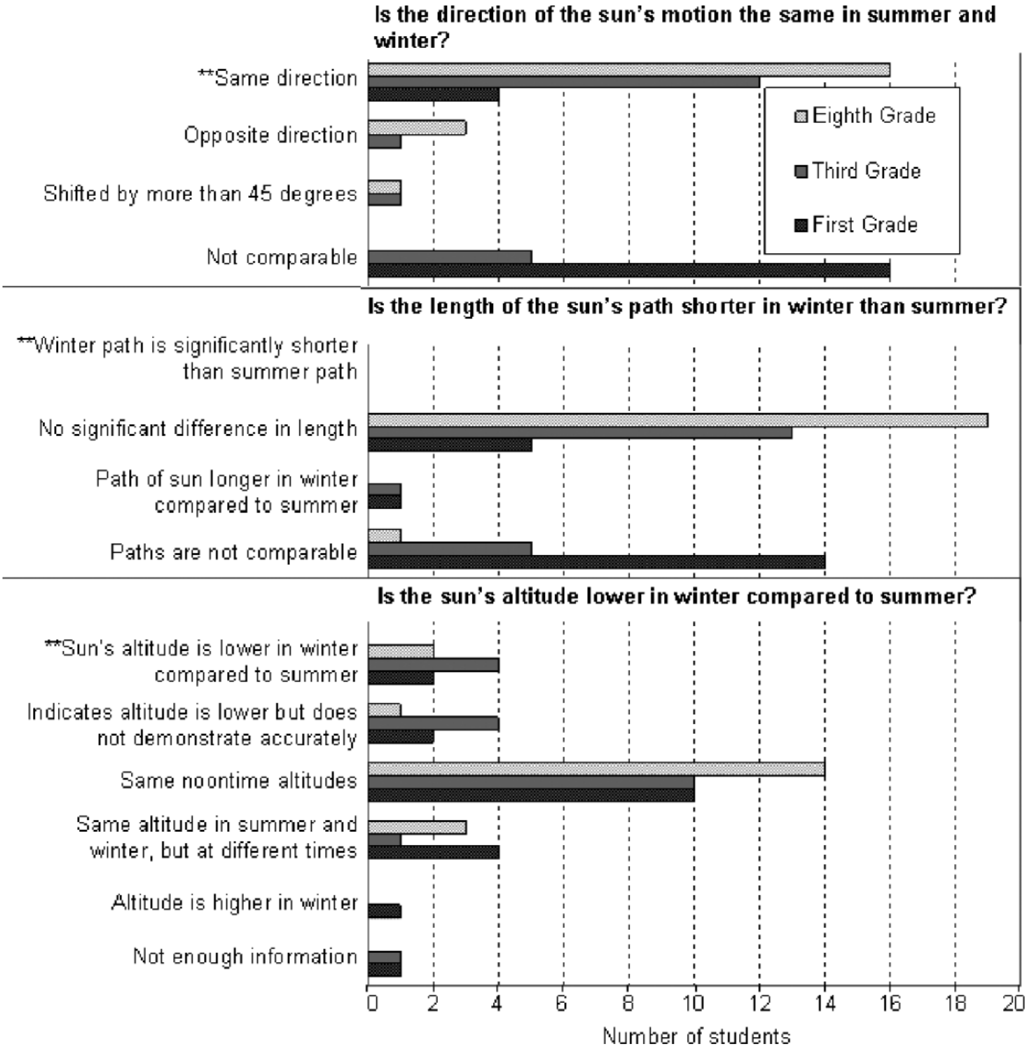


Figure 5. The seasonal comparison of the Sun's apparent motion. Reading down the graph indicates the frequency (out of 20) of students holding that conception for each category, by grade level. The accurate response for each category is indicated by **

first-graders could only describe one shape of the Moon. The other three first-grade students were able to draw more than one shape for the Moon but these included some inaccuracies, such as drawing a 'half moon' as a crescent moon with a line bisecting it horizontally. One of these first-grade students indicated a difference between the Moon in the real sky and in fairytales:

Alicia: It can be two different ways. In a fairy tale and real. [She points to her drawings of the crescent and full Moon, respectively.]

| | |
|---|---|
| Interviewer: | OK, so that's real [pointing to the full Moon] and— |
| Alicia: | And that's a fairy tale. Yeah, two different ways. |
| Interviewer: | Do we see the moon in the sky both of those ways? |
| Alicia: | This one would, this would be in the ah, the fairy tale. When they draw pictures of ⟨***⟩. This would be here. In real life. |
| Interviewer: | So in real life, does the moon change its shape in the sky? |
| Alicia: | Hmm, no. |
| Interviewer: | Why do they draw the moon differently for fairy tales? |
| Alicia: | Because some people don't know what the moon looks like sometimes. |

Alicia is an interesting example of a young child beginning to operate in two different domains of knowledge (Solomon, 1983). For her, the appearance of the Moon is tied to the situation in which she considers it. The Moon in the sky and the Moon in a make-believe world do not follow the same rules. Children like Alicia, who separate the properties of astronomical objects into two domains, face the difficult challenge of reasoning between everyday situations and the symbolic knowledge of the scientific domain (Donaldson, 1978; Solomon, 1983).

Most first-grade students gave non-scientific responses for the length of time it takes for the Moon to change its shape. About one-half of the students believe that the Moon's appearance can change from one phase to another in less than 1 day, and another one-quarter were not sure how long it takes for the shape of the Moon to change. There were also inaccuracies in the four first-grade students (20%) who said that the Moon's appearance would not change, or only change very slightly, in less than 1 day (e.g., it takes an entire year for the Moon to go through phases, or clouds are responsible for the Moon's changing shape). Slightly more than one-half (55%) of the third-grade students knew that we would not see a noticeable change in the phase of the Moon during the night. The majority of the eighth-grade students (70%) understood the amount of time it takes for the shape of the Moon to appear to change. Inaccuracies in the remaining eighth-grade students included the belief that the appearance of the Moon will change significantly in a single night (three students) and the apparent shape of the Moon never changes (two students).



### *Apparent Path of the Moon*

Just as with the Sun, the students demonstrated a wide range of ideas about the apparent motion of the Moon (see Figure 7). Most of the first-grade students (55%) described the Moon's motion as rising straight up to the zenith, remaining there throughout the night, and then setting at the end of the night. Aletta's answer is a typical response for this group; when it was almost time for morning, she said 'And they're trading. The Sun's going to trade with the Moon'.

The most common response from the third-grade students was to describe the Moon's apparent motion as a smooth curve across the sky, either through the zenith (55%) or just below it (5%). The next most common description (20%) was to indicate that the Moon rises and sets in the same place on the horizon. Most of the eighth-grade students also described the Moon's motion as a smooth path across the

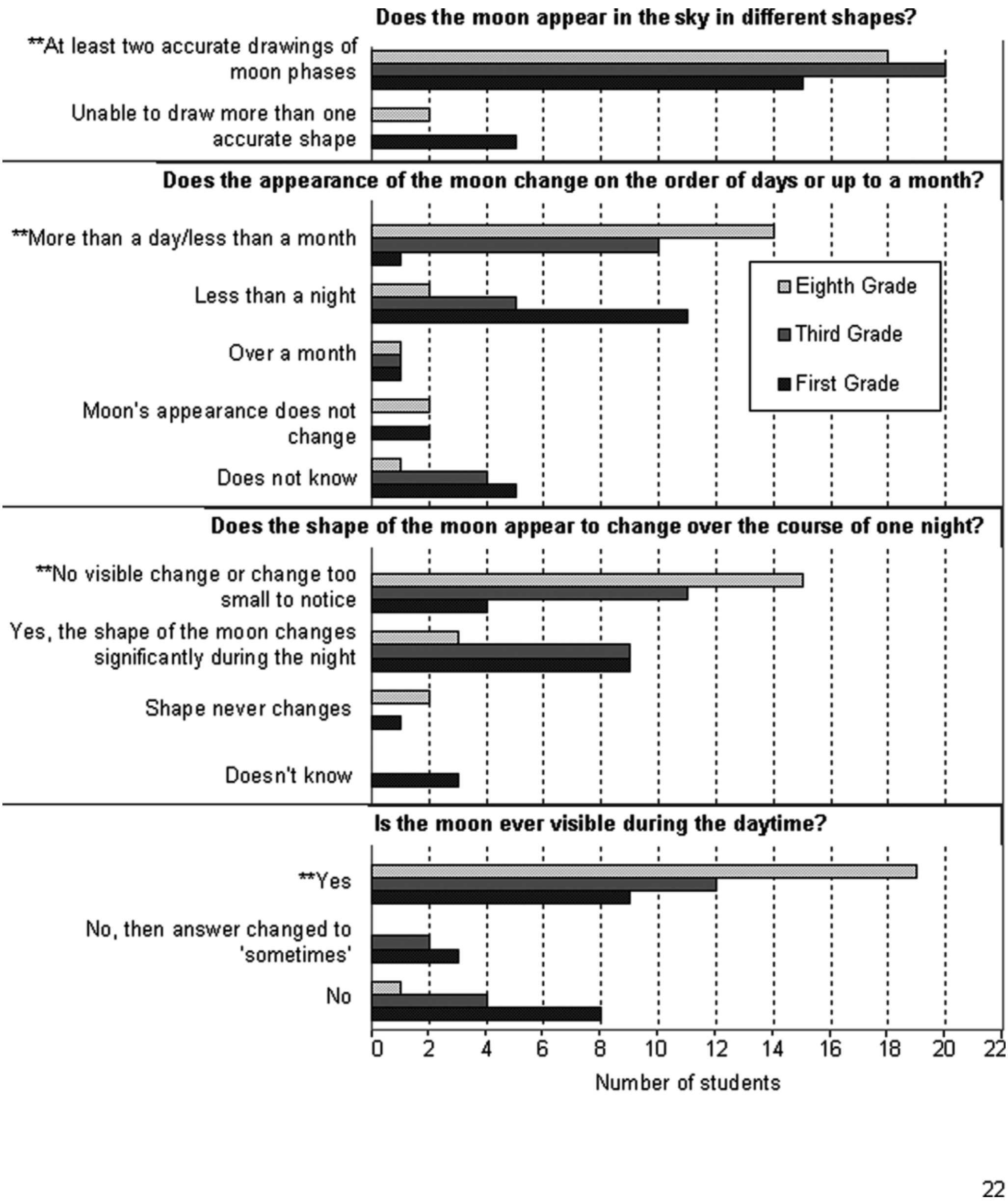


Figure 6. The appearance of the Moon. Reading down the graph indicates the frequency (out of 20) of students holding that conception for each category, by grade level. The accurate response for each category is indicated by **

sky through the zenith (55%). A large number of students indicated that the Moon is always in the sky and never sets: two (10%) third-grade students and seven (35%) of the eighth-grade students. The students who indicated that the Moon is always in the sky included four students who showed the Moon circling around the sky, two

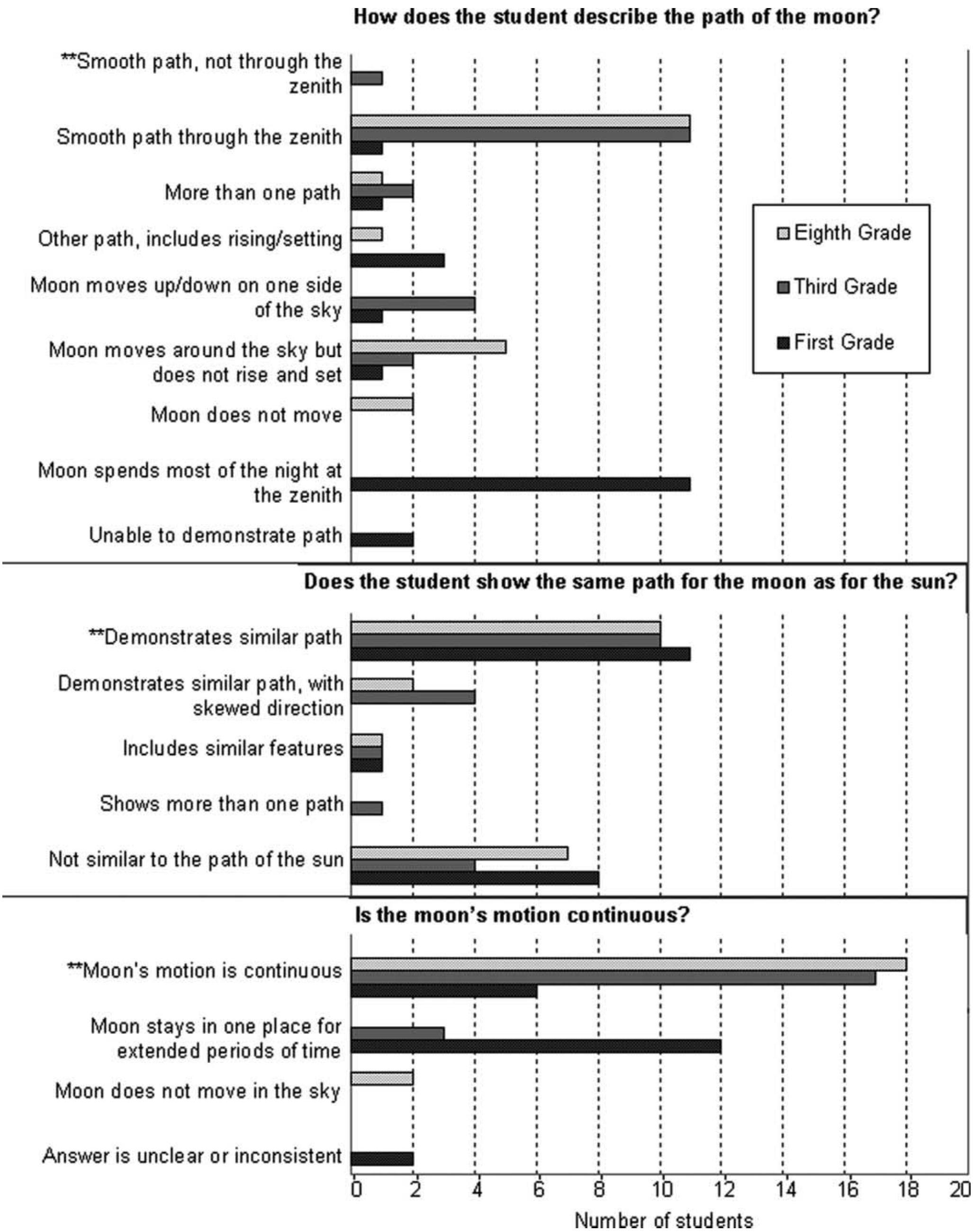


Figure 7. The path of the Moon. Reading down the graph indicates the frequency (out of 20) of students holding that conception for each category, by grade level. The accurate response for each category is indicated by **

students who said the Moon only moves a little, one student who showed the Moon moving back and forth, and two students who indicated that the Moon never moves.

Some of the eighth-grade students used their knowledge of the Earth's motion to explain their non-scientific ideas about the Moon's motion. Rick demonstrated the Moon circling around the sky:

| | |
|---|---|
| Interviewer: | What's going to happen to the moon from say, sunset until midnight? |
| Rick: | It like, ah, the moon like rotates around the earth so I don't know … that's a tough one. |
| Interviewer: | So if you thought about, like through the entire night, what might the moon do? |
| Rick: | It moves, like in a circle, maybe? [He shows the Moon making a circle.] |
| Interviewer: | So does it come back to the same spot by the end of the night? |
| Rick: | No, probably about half way. It takes about 24 hours. Some ⟨*⟩ takes about a day to go around and get back to the same spot. |
| Interviewer: | So when the sun comes up again in the morning, what happens to the moon? |
| Rick: | The moon, [3-second pause] I don't know. I would think it goes around the earth and … |
| Interviewer: | So is the moon always in the sky? |
| Rick: | Yeah |

Rick inaccurately describes the apparent motion of the Moon, and attempts to explain these apparent motions by the inaccurate use of the Moon's orbit around the Earth. Jason used the Earth's motion to explain that the Moon does not move. When asked whether the Moon's position in the sky will change during the night, he responded: 'I don't think so. I think it's just that we rotate, the Earth rotates. The Moon kind of stays there'. These students' attempts to describe the Moon's apparent motion suggest that they have not accurately integrated the Moon's orbit or the Earth's rotation into their understanding of the Moon's apparent motion.

The actual path of the Sun and Moon are quite similar because they are both caused by the rotation of the Earth on a day-to-day basis. Across the three grade levels there was no significant difference in the number of students who showed the same path for the Sun and Moon (see Figure 7), $\chi^2(1, n = 60) = 0.133, p > .05$. This does not mean that the students in all grades were showing the same paths for the Sun and Moon; there is a significant difference in the most common path of the Moon shown by the first-grade students compared with third-grade and eighth-grade students. Even though there was a significant difference in the most commonly expressed type of path for the Moon and the Sun *between* grade levels, *within* grade levels the students showed the same level of consistency in describing the path of the Sun and the Moon. This suggests that, as students' understanding of the apparent motion of the Sun changes, it extends to how they will explain the motion of the other celestial object.

Most of the first-grade students (60%) did not describe the Moon's apparent motion as continuous. A few of the third-grade students (15%) and eighth-grade students (10%) also indicated that the Moon does not move at times. Two eighth-grade students suggested that the Moon never appears to move in the sky, a concept not seen in any of the younger students, suggesting this may be an idea that developed after early elementary school.

### *Apparent Motion of the Stars*

Most of the eighth-grade students were split between those who could give a general description of the stars moving slowly across the sky during the night (40%) and those who did not think that the stars ever seem to move (40%) (see Figure 8). The remaining students were split between the belief that the stars only move at the end of the night and the belief that the stars appear to move, but gave an inaccurate description of the movement. Although not asked to explain this motion, six of the eighth-grade students mentioned the rotation or spinning of the Earth, including the two students who said that the stars only move at the end of the night. Marina initially said that a star will stay in the same place throughout the night, although her answer seems to change as she considers what we would see over the entire night:

| | |
|---|---|
| Interviewer: | If we go outside just before sunrise while it is still dark and we can still see the stars, would we see the same stars that we saw just after sunset? |
| Marina: | Maybe not because like the s—, the earth rotates so you get different stars. |
| Interviewer: | So we might see other stars then. Would we see any of the same stars? |
| Marina: | We might. Maybe a couple. Maybe the brightest ones. Not like the ones that pretty much disappear. |
| Interviewer: | And would those ones be in the same place or a different place? |
| Marina: | They might move a little. Not like too much though. |

Students who said that the stars do not seem to move did not mention the Earth's rotation.

The third-grade students were also closely split between students who think the stars move during the night (50%) and the students who do not think the stars move at all (40%). The remaining students believe the stars only move at the end of the night (10%). Even though one-half either could describe the stars as appearing to move smoothly across the sky, or moving but with inaccuracies in the descriptions, only one student indicated that the stars appear to move because of the Earth's rotation. The remaining students, who indicated that the stars appear to move, either did not explain the motion (three students) or used alternative ideas in their explanations (five students): three of the students mentioned the stars needing to be with the Moon and the other two described the stars as floating, such as Misty who said 'They move because they are big balls of gas floating in outer space'.

The first-grade students understanding of the stars was primarily split between three codes: the stars never appear to move (25%), the stars do appear to move throughout the night (35%), and the stars only move at the end of the night when they set (30%). Only one of the first-grade students described a smooth path for the stars, although this included inaccuracies; she demonstrated that a star may move up during the night and then set back down after midnight.

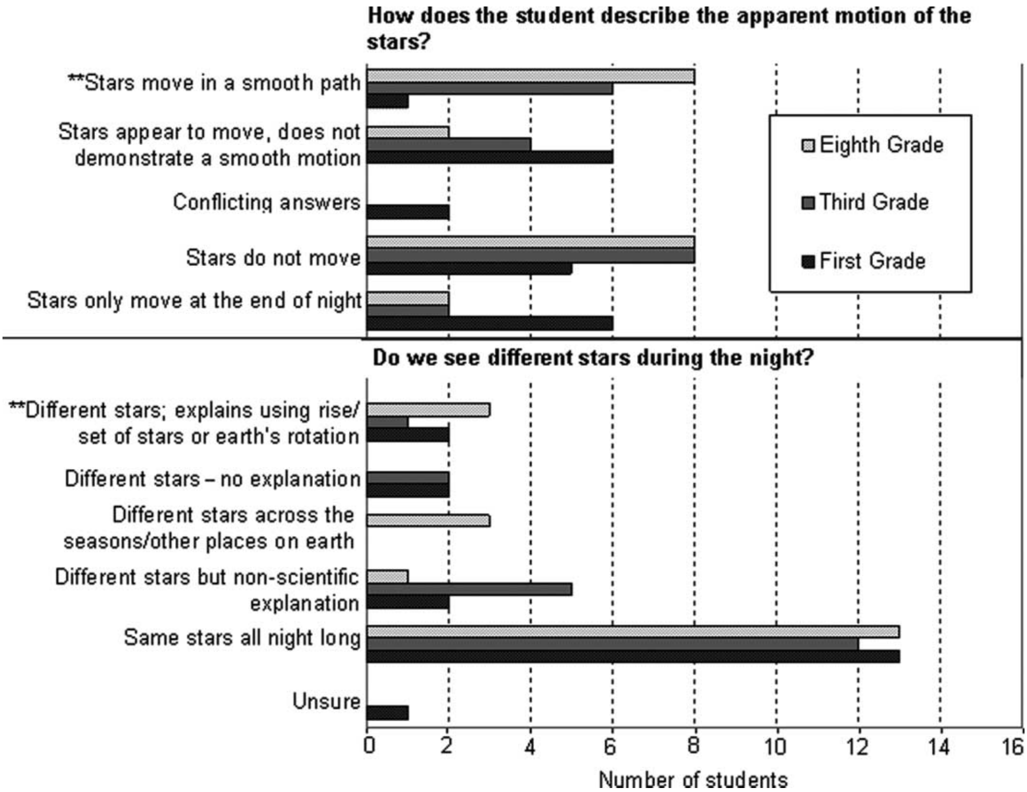


Figure 8. The apparent motion of the stars. Reading down the graph indicates the frequency (out of 20) of students holding that conception for each category, by grade level. The accurate response for each category is indicated by **



Students were asked whether or not we see the same stars just before sunrise as we see just after sunset, as another way to find out about their understanding of the apparent motion of stars. Over one-half of the students in the first, third, and eighth grades do not think that we see different stars in the sky during the night (65%, 60%, and 65%, respectively). A few students in each grade used the concept of rising and setting in their description of why we see different stars throughout the night. Two of the eighth-grade students and one third-grade student used the rotation of the Earth to explain why we see different stars during the night. The remaining students had no explanation or a non-scientific explanation.

## Discussion: Children's understanding of celestial motion

The first-grade, third-grade, and eighth-grade students in this study demonstrated a range of alternative ideas about the apparent motion of the Sun, Moon, and stars. While in some areas there was an increase in the number of students showing more scientific understanding from younger to older students, this positive change often did not reach a fully scientific understanding of the patterns of motion. And for some concepts, there was no difference when comparing the elementary students with the middle school students.

### *Apparent Motion of the Sun, Moon, and Stars*

Most first-grade students do not yet understand that all celestial objects appear to move continuously across the sky as they rise and set, in the same direction, and along similar paths. Many believe that the Sun and Moon rise up to the zenith, remaining there without moving, and then set, rather than moving continuously across the sky. This is similar to some of the students' belief that the stars appear in the sky unmoving throughout the night and then move down below the ground or to where the Moon is at the end of the night. More first-grade students believe that the stars never move, or are unable to describe their motion. Their ideas are not surprising considering that students at this age have had limited opportunities to observe the changing location of celestial objects or to learn about their motions in schools. Their descriptions match simple observations such as the Sun is 'up' in the sky during the day and 'down' and night.

Third-grade students exhibited a higher level of accuracy in their answers compared with the first-grade students. Most have made the shift to viewing celestial objects as moving slowly across the sky rather than staying fixed in the sky between rising and setting. There are also a substantial number of third-grade students who have some of the same non-scientific views of the apparent motion of the Sun, Moon, and stars as the first-grade students. The majority of third-grade students believe that the Sun has a smooth path across the sky through the zenith or that the Sun rises and sets in the same place in the sky, and use the same descriptions for the Moon's motion as the Sun. They are more likely than first-grade students to be able to describe and demonstrate that the stars appear to move across the sky during the night. However, the same large fraction of students believes that the stars never move; there is no improvement in the concept that we see different stars throughout the night.

The eighth-grade students demonstrated a more scientific understanding of the apparent motion of the Sun, but not for the Moon or stars. All of the eighth-grade students demonstrate that the Sun rises and sets on opposite sides of the sky. Almost all described this motion as a smooth path across the sky, although the misconception that the Sun passes directly overhead was just as prevalent among older students as with younger students. No improvement was seen in the accuracy of understanding of the motion of the Moon among eighth-grade students. Even though slightly more than one-half of the eighth-grade students describe the Moon as smoothly rising and setting on opposite sides of the sky, a large number of the students claimed that the Moon is always in the sky (more than in the younger grades). Similarly, there is no significant improvement in the responses given by eighth-grade students compared with the third-grade students concerning the apparent motion of the stars or the idea that we see different stars throughout the night.

While it is notable that eighth-grade students are no more accurate in their understanding of the apparent motion of the Moon or stars than third graders, this may not be surprising. Children do not have many opportunities to make the kind of direct observations that would improve their understanding of this phenomenon. The necessary observations are difficult for children and adults alike; few people have the time or inclination to conduct a day or night's worth of observations or to extend those observations over months. Further, US culture does not encourage children to stay outside at night to look at the stars, regardless of whether they are in an urban or suburban setting. Given that adults are not likely to have an accurate knowledge of apparent celestial motion (Mant & Summers, 1993), it is also worth considering that children may be receiving inaccurate instruction from parents and teachers.

Many of the eighth-grade students mentioned the Earth's rotation in their interviews; clearly they have learned about this concept. The rotation of the Earth is a common concept covered in elementary astronomy instruction in the USA (Palen & Proctor, 2006). Thus the lack of improvement by the eighth grade suggests that previous instruction on the Earth's actual motion has not helped students make the connection between the rotation of the Earth and the resulting apparent daily motion of the Moon and stars.

Sharp (1996) found that about three-quarters of the 10-year-old and 11-year-old students in his study understood that the Sun rises and sets, moving across the sky, consistent with the results of the students in the third and eighth grades in the present study. However, Sharp found far fewer students (36%) who believe the Moon appears to move compared with this study (100% of third-grade and 90% of eighth-grade students). Similarly, Sharp found that only 14% of the students were aware of the stars' apparent motion, compared with 60% of both the third-grade and eighth-grade students in this study. This difference may be due to the difference in interview methodology. Sharp's study coded the children's understanding based on verbal responses, the use of a sketch and/or a gesture rather than demonstrations and verbal responses in a simulated sky.

Mant and Summers' (1993) study of elementary teachers found results similar to the eighth-grade students in this study in their basic description of the Sun's path but not in their description of the Sun's highest altitude; 19 of 20 teachers said that the Sun does not pass directly overhead, compared with only two of the eighth-grade students. Other studies of middle school students agree with the present study's findings. Lightman and Sadler (1993) found that only 8% of US students surveyed knew that the Sun never passes directly overhead. Trumper (2001) found that 32% of Israeli middle school students surveyed gave an accurate response to this question.

Twenty percent of the teachers in Mant and Summer's (1993) study said that the Moon does not appear to move during one day, compared with 10% of eighth-grade students. Eighty-five percent of the teachers who said that the Moon appears to move were described as 'path unknown', although some of these did include rising and setting. Mant and Summers' interview setting may have limited the subjects' ability to describe apparent motion. The teachers had a similar level of knowledge of the apparent motion of the stars; 60% gave a description of the apparent motion of the stars, compared with 50% of the eighth-grade students in this study. While experience and education may have improved the teachers' knowledge of the motion of the Sun compared with younger students, this did not extend to the Moon and the stars.

### *Seasonal Change in the Sun's Path*

Overall, there is no increase in the level of accuracy in understanding of seasonal change between the third-grade and eighth-grade students. Almost all of the third-grade and eighth-grade students describe the Sun as having the same length of path in summer and winter. Similarly, very few students at each grade level know that the Sun is lower in winter than summer, and there is no improvement seen when comparing older with younger students. A much higher percentage of the teachers in Mant and Summers' (1993) study knew that the Sun is higher in summer than in winter, compared with the eighth-grade students in this study (85% and 15%, respectively). This may suggest that knowledge of the pattern of the Sun's motion may improve after middle school due to additional years observing the change in the Sun's altitude across seasons, or perhaps teachers have more opportunities to learn this concept as part of planning for science instruction.

### *Apparent Change in the Appearance of the Moon*

This study found that most students are able to draw at least two different and accurate shapes for the Moon (for a more detailed examination of fourth-grade students' knowledge of the phases of the Moon, see Trundle, Atwood, & Christopher, 2007). There is a clear shift towards accuracy with increasing grade in knowledge of the amount of time it takes for the appearance of the Moon to change. The students in the first grade may not have learned about the phases of the Moon and how long it takes to go through a complete cycle and may have had fewer opportunities than the older children to make their own observations of changes in the Moon's appearance. The same number of first-grade and third-grade students said that it takes less than a night for a significant change in the appearance of the Moon. Some of this may be attributed to students who believe that the phases of the Moon are caused by the movements of clouds in front of the Moon (Baxter, 1989). Even though most of the eighth-grade students were aware of the time taken for the Moon to go through its phases, it is unlikely that most of the eighth-grade students would have given the accurate explanation for what causes the changing appearance (Baxter, 1989). It is more likely that the improved knowledge comes from learning in school the length of time to complete a cycle of Moon's phases rather than understanding the full explanation of why the phases of the Moon change.

## Implications and Future Research

While middle school students show a more scientific understanding of the daily apparent motion of the Sun, they show far less positive change across other areas of apparent celestial motion; none of the grades in this study can be characterised as having the level of understanding of apparent celestial motion described by the NSES (NRC, 1996) and the Benchmarks (AAAS, 1993) for elementary grades. Even though the concepts of apparent celestial motion may be thought of as low-level descriptive skills, the lack of knowledge about the patterns of apparent celestial motion have consequences for other more advanced areas of scientific knowledge. Students do not have the observational knowledge to apply to learning other concepts, such as the explanation of the seasons or phases of the Moon.

The results of this study demonstrate the need for further research on successful instructional strategies relating to apparent celestial motion for teaching early elementary students. Successful instruction will need to consider that children's ideas about the apparent motion of the Sun, Moon, and stars are not primarily based on accurate observations of these objects in the sky and will be able to provide convincing alternatives to the common non-scientific ideas presented in this paper. These non-scientific ideas may hinder students from accurately incorporating the actual motions of celestial objects into their understanding as well. A planetarium programme that engages students through kinaesthetic instruction has been shown to be successful for improving first-grade and second-grade students' knowledge in all areas of apparent celestial motion covered in this study (Plummer, 2006). However, that study only examined the impact of a single 45-minute planetarium programme with post-instruction interviews conducted one week later. Further research should examine the long-term durability of concepts learned in the planetarium, compare with additional instructional designs for the planetarium, and investigate how these concepts can be used in cooperation with classroom instruction. Research on classroom instruction for these concepts should be conducted because not every teacher has access to a planetarium. Such research could involve instruction that uses desktop planetarium programmes to demonstrate celestial motion, although such research may need to consider whether the two-dimensional representation is problematic for developing understanding. Instruction that uses children's own observations of the Sun, Moon, and stars could also be compared to instruction that simulates the real sky (planetariums and computer programs).

Alternatively, what is the impact of instruction that covers actual celestial motion without also covering apparent celestial motion? The results of this study suggest that such instruction will not lead to an accurate understanding of apparent celestial motion. Many of the eighth-grade students' answers showed that they know about the rotation of the Earth, often in relation to their description of the motion of the Sun. However, this knowledge did not lead to a corresponding knowledge of the pattern of motion of the Moon or stars. The specific difficulty lies in students' ability to translate from one frame of reference to another frame of reference, made more complex because of the system is in motion. Therefore, instruction that is successful in improving knowledge of all aspects of celestial motion must explicitly help students understand both frames of reference in order to connect the concepts of rotation and revolution to the observed patterns we see in the sky.

Explaining observations of objects beyond the Earth is a key aspect of scientific work in the field of astronomy. Children can begin to understand this aspect of astronomy by studying the patterns of motion of the Sun, Moon, and stars and then learning to explain these motions using the scientific model of the Earth's rotation and revolution. Both the NSES (NRC, 1996) and the Benchmarks (AAAS, 1993) recommend that students learn science through inquiry by learning to explain their observational knowledge of the world. If the consensus among science educators is that students should learn science concepts in combination with inquiry process skills, then instructional goals in astronomy should emphasise the practice of explaining observational data with theory. One example successfully demonstrating this approach to elementary astronomy education is a study by Trundle et al. (2007), who have shown that instruction combining the understanding of patterns of motion with the explanation for these changes can improve fourth-grade students' understanding of both the apparent and actual aspects of the phases of the Moon.

The next step is to investigate instruction that helps students learn to explain the patterns of motion using the actual motion of the Earth and Moon. It may be that most students are not able to develop a fully scientific description of the patterns of apparent celestial motion without also understanding the underlying explanations for these motions, including the shape of the Earth and gravity. Studies of early elementary students' learning about the shape of the Earth and gravity have shown moderate success (Kikas, 2006; Nussbaum & Novak, 1976; Nussbaum & Sharoni-Dagan, 1983), while studies of older elementary students have shown greater improvement in understanding (Diakidoy & Kendeou, 2001; Sneider & Ohadi, 1998). The results of studies detailing the importance of children's geographical awareness (Siegal et al., 2004) and their use of cultural tools such as globes and maps (Ivarsson et al., 2002; Schoultz et al., 2001) suggest that these are areas in which to explore further in studies of younger children learning about the shape of the Earth. Thus, addressing the connection between apparent celestial motion and the Earth's actual motion may also require additional research on instruction designed to teach children the scientific concept of the shape of the Earth. The results will help us determine the most successful placement of celestial motion concepts along a learning progression (Duschl, Schweingruber, & Shouse, 2007).

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