A LIVELY ELECTRONIC COMPENDIUM OF RESEARCH, NEWS, RESOURCES, AND OPINION

Astronomy Education Review

Volume 7, Feb 2008 - Dec 2008
Issue 1

Students' Development of Astronomy Concepts across Time

by **Julia Plummer**
Arcadia University
Received: 03/28/08, Posted: 05/22/08

The Astronomy Education Review, Issue 1, Volume 7:139-148, 2008

Abstract

Students in Grades 1, 3, and 8 ($N = 60$) were interviewed while using a planetarium-like setting that allowed the students to demonstrate their ideas about apparent celestial motion both verbally and with their own motions. Though the older students were generally more accurate in many conceptual areas compared with the younger students, in several areas, the eighth-grade students showed no improvement over the third-grade students. The use of kinesthetic learning techniques in a planetarium program was also explored as a method to improve understanding of celestial motion. Pre- and postinterviews were conducted with participants from seven classes of first- and second-grade students ($N = 63$). Students showed significant improvement in all areas of apparent celestial motion covered by the planetarium program and surpassed the middle school students' understanding of these concepts in most areas. Based on the results of these studies, a learning progression was developed describing how children may progress through successively more complex ways of understanding apparent celestial motion across elementary grades.

1. INTRODUCTION

This study addresses children's knowledge of *apparent celestial motion*: any of the observable patterns of motion of the Sun, Moon, and stars that occur in daily, monthly, and yearly patterns. Both the *National Science Education Standards* (*NSES*; National Research Council 1996) and the *Benchmarks for Science Literacy* (*Benchmarks*; American Association for the Advancement of Science [AAAS] 1993) include the patterns of celestial motion as learning goals for early elementary school. There are several reasons why children may benefit from learning about apparent celestial motion. First, a scientifically literate individual has developed an understanding of the aspects of astronomy visible, from our own Earth-based perspective, without the aid of a camera or telescope (AAAS 1989). Second, most instruction fails to help students make the connections between the observed motions in the sky and the deduced motion of the planets, Sun, and Moon from an outside perspective (Nussbaum 1986). This may be due partly to a lack of emphasis on understanding these patterns of motion from the learner's own perspective. Instruction that focuses primarily on the heliocentric motions not only is unlikely to improve knowledge of apparent motion but may also result in nonnormative ideas about celestial motion. Finally, knowledge of the apparent motion of the Sun and Moon may be important in developing a scientific understanding of phenomena that are commonly not understood by children or adults: the seasons (Atwood & Atwood 1996; Baxter 1989; Trumper 2006) and phases of the Moon (Barnett & Morran 2002; Baxter 1989; Kavanagh, Agan, & Sneider 2005; Stahly, Krockover, & Shepardson 1999; Trundle, Atwood, & Christopher 2007).

First, all these motions occur over long periods of time—hours in the case of the daily motion of the Sun, Moon, and stars; daily for the shift in the Moon's appearance and rise/set time; and monthly for the slow change in the Sun's path across the seasons and in the constellations we see each night. Second, tracking these motions requires significant effort to notice and recall positions with respect to landmarks on the horizon. Third, these changes often occur at night, when many children and adults are not outside observing the sky. Therefore, it is unlikely that most children have made the observations necessary to learn the details of apparent celestial motion.

The *NSES* and *Benchmarks* provide a summary of objectives relating to apparent celestial motion that are intended to help in the design of curricula and assessments for early elementary students, but these objectives lack support from research on children's knowledge of these topics and the steps that students may move through in the process of learning these concepts. Using research on children's reasoning and learning in science, we can elaborate on the *NSES* and *Benchmarks* in ways that can be used to help teachers, curriculum developers, and assessment writers improve their practice (Duschl, Schweingruber, & Shouse 2007; Smith et al. 2006). These elaborations would create *learning progressions*: "descriptions of successively more sophisticated ways of reasoning within a content domain based on research syntheses and conceptual analyses" (Smith et al., 3). Learning progressions focus on the "big ideas," or central principles of the domain, which will allow coherent curricula to be developed and assessments to be aligned with the central aspects of scientific understanding in the field. A learning progression is not an inevitable progression that all students will move through toward a scientific understanding; rather, it depends on the instruction that students receive.

Creating a learning progression requires a basis in research that provides empirical evidence of children's understanding of celestial motion, both in terms of their prior knowledge and what they are capable of with well-designed instruction. This presents a problem. Reviews of astronomy education literature reveal a scarcity of research on children's ideas about apparent celestial motion (Adams & Slater 2000; Bailey & Slater 2003). Studies of apparent celestial motion with children (Sharp 1996) and adults (Mant & Summers 1993; Trumper 2006); the Earth as a cosmological object (Agan & Sneider 2003; Bryce & Blown 2006; Klein 1982; Nussbaum & Novak 1976; Nussbaum 1979; Sneider & Ohadi 1998; Sneider & Pulos 1983; Vosniadou & Brewer 1992); and the relationships among the Earth, Sun, Moon, and stars (Bryce & Blown 2006; Diakidoy, Vosniadou, & Hawks 1997; Klein 1982; Samarapungavan, Vosniadou, & Brewer 1996; Siegal, Butterworth, & Newcombe 2004; Vosniadou & Brewer 1994) suggest that young children do not understand most aspects of apparent celestial motion. In addition, Trundle et al. (2007) have reported on instruction that improved children's understanding of the change in phases of the Moon by having students use their own observations of the Moon in the sky. Aside from this, there have been no studies of instruction designed to improve children's understanding of these topics in order to establish successful techniques and settings or to provide evidence for the age-appropriate nature of these concepts.

This dissertation begins the process of creating a learning progression for apparent celestial motion first by assessing children's knowledge of apparent celestial motion across elementary and middle grades (Study A), and then by investigating the effect of instruction on these concepts (Study B). Study A was guided by the following research questions: (1) What are students' conceptions of the patterns of motion of the Sun, Moon, and stars as viewed from the Earth? (2) Do students' conceptions of the patterns of motion of the Sun, Moon, and stars change with grade?

The planetarium can be used to allow students to view the motion of celestial bodies in a way that they are unable to do on their own because the planetarium instrument can project a day's worth or even a year's worth of motion in a matter of minutes. Unfortunately, very few studies have examined planetarium instruction based on a modern understanding of how people learn (Bishop 1980; Mallon & Bruce 1982; Fletcher 1980).

The instruction for Study B was designed to build on children's prior knowledge of celestial motion, using the results of Study A, and to engage students as active participants in the planetarium program. This participation took the form of kinesthetic learning techniques (KLTs). These KLTs were designed to focus the children's attention on the key topics of apparent celestial motion. First, the children used their hands and arms to make predictions about what the apparent motion of the Sun, Moon, and stars would look like in the sky, based on their prior knowledge or previous observations made in the planetarium. Second, the children were asked to point to and then follow the motion of objects as they were demonstrated throughout the program. Throughout the program, students were guided to use kinesthetic learning techniques in ways that would engage them in comparing their initial descriptions with the scientific view. Study B was guided by the following research questions: (1) Did students improve their knowledge of the patterns of motion of celestial objects after participating in a planetarium program that uses KLTs? (2) Did students learn about additional topics covered in the planetarium program that were not taught by the use of KLTs?

2. METHODOLOGY

For Study A, I interviewed 20 children from first, third, and eighth grades ($N = 60$). Interviews were conducted one on one within a small dome (4' in diameter) that was used to represent the sky. The student used the flashlight to indicate his or her ideas about the apparent motion of the Sun, the Moon, or a star by pointing out how the location of these objects may change on the interior of the dome-sky. Codes were developed for each of the categories of apparent celestial motion examined in this study. The codes included both the accurate description of these concepts and the alternative ideas demonstrated and indicated verbally by students during the interviews.

Study B investigated the use of a 45-minute program with seven classes of first- and second- grade students. Eight to ten students per class were randomly selected for pre- and postinterviews ($N = 63$). The same interview protocol and coding scheme from Study A were used. A numeric value was assigned to each code for use in the statistical analysis: *accurate* was designated as 3; *partially accurate* as 2, and *nonnormative* as 1. The Wilcoxon matched-pairs signed-ranks test was used to determine whether the distribution of scores from two correlated samples (pre- and postinstruction results) was significantly different for each category.

3. STUDY A--ANALYSIS AND RESULTS

In all areas of apparent celestial motion, most of the students at each grade level held nonnormative beliefs about the concepts examined, though there was a shift toward the scientific concepts when comparing third grade with first grade in most areas (except the seasonal change of the Sun and the apparent motion of the stars). However, the eighth-grade students continued to hold many of the same nonnormative ideas as the younger students in numerous areas regarding the apparent motion of the Sun, Moon, and stars. There was no significant improvement found in the eighth-grade students compared with the third-grade students in their understanding of the Sun's highest altitude, change in the Sun's path across seasons, path of the Moon, and motion of the stars. A complete treatment of the results of this study is forthcoming (Plummer 2008a).

The mini-dome environment used in the interview expanded what could be learned about children's ideas regarding apparent celestial motion beyond previous techniques: verbal questions, the use of spherical models of the objects, and drawings. It allowed the students to recreate the motions that they can imagine observing in the sky without relying on their limited vocabulary to describe their ideas. It also aided in communication between the interviewer and the interviewee by allowing concepts such as continuity of motion, directionality, and altitude to be expressed by the child without the necessity of translating those concepts from verbal or 2-D representations.

4. STUDY B--ANALYSIS AND RESULTS

Six subquestions to Research Question 1 were analyzed on the topics of the apparent motion of the Sun in summer and winter, comparison of the Sun's motion across seasons, the apparent motion of the Moon, the apparent motion of the stars, and what happens to make it day. These corresponded to the six concepts covered during the planetarium program using the KLTs. Four subquestions to Research Question 2 were analyzed on the topics of the length of time for the Moon's appearance to change, the Moon's visibility during the daytime, and the explanation for why we cannot see the stars during the day. These correspond to topics that were part of the program but not covered using the KLTs. A statistical analysis comparing the students' pre- and postvisit answers for each category showed significant improvement for all topics at the $p < 0.001$ level, except for "what happens to make it day" and "the appearance of the Moon during the day," which showed significant improvement at the $p < 0.05$ level. Further details concerning this study are forthcoming (Plummer 2008b).

The students showed the most improvement on the topics relating to the Sun's apparent motion and the Moon's apparent motion, with more than half of the students demonstrating improved understanding. Fewer than half of the students showed improvement in their knowledge of the patterns of motion of the stars (41%) and in their knowledge that we see different stars throughout the night (48%). About a third of the students continued to give nonnormative responses in their postinstruction interviews about these two concepts (27% and 33%, respectively). Students may have shown greater improvement for the Sun and Moon compared with the stars because they have greater prior knowledge about those subjects. The stars also present a more challenging system in which to notice change as compared with single objects such as the Sun and Moon; the stars are only visible at night, when children are likely to be indoors or asleep.

There are several ways that instruction in the planetarium program can account for the significant improvement seen in the students' understanding of celestial motion. First, the students were actively engaged throughout the planetarium program rather than passive observers. The students were asked to demonstrate their initial understanding of apparent celestial motion in order to activate the appropriate areas of their memory tied to these astronomy topics. They then had the immediate opportunity to compare their prior ideas with the accurate demonstration of motion while they followed the Sun, Moon, or stars with their arms and bodies. This activity may have prompted conceptual change through a form of kinesthetic cognitive conflict (Druyan 1997). Second, the planetarium environment focused the students on the topics by explicitly demonstrating the concepts in a visually rich fashion. Because the planetarium is not limited by time, weather, or the brightness of celestial objects, the students experienced a simulation of the actual patterns of motion across the day and night sky that went beyond what they could ordinarily observe. Finally, I was able to guide the students' attention toward the important concepts of celestial motion through the use of the KLTs, thus minimizing distractions that could have prevented students from noticing key aspects of the motion.

The kinesthetic learning techniques may have helped the students learn in other ways beyond just focusing their attention on the patterns of motion. Some of the power of KLTs may derive from students encoding information in multiple modalities. Dual-coding theory suggests that there are separate cognitive processing systems for verbal and nonverbal experiences (Paivio 1986). Previous studies have also suggested that students show improvement via the dual coding of kinesthetic and visual or auditory stimuli in studies about length, balance, and speed (Druyan 1997) and in nanoscale science using haptic feedback with computer visualizations (Jones et al. 2006). The students were forming kinesthetic imagery stored in their memories in a similar fashion to the visual imagery also processed during the planetarium program. By working through these concepts in both the kinesthetic and visual sense together, they can be accessed simultaneously in coordination with the verbal cues at a later time.

5. DEVELOPMENT OF THE LEARNING PROGRESSION

To begin the development of a learning progression, the central concepts of apparent celestial motion were separated into two "big ideas" that tie together similar observational patterns. The first big idea states that the Sun, Moon, and stars all appear to move slowly across the sky with a regular pattern of motion. This was broken into separate strands for the Sun, the Moon, and the stars for the progression. The second big idea describes the apparent change in the Moon's appearance over the course of a month. This dissertation describes how the results of Studies A and B, as well as previous research on children's ideas about astronomy, support the placement of each step along the learning progression. An example of one aspect of the learning progression is described below: how the research in this study supports placing specific concepts as targets for the Grades 2–3 level on the learning progression strand for Big Idea 1A—the apparent motion of the Sun (Figure 1).

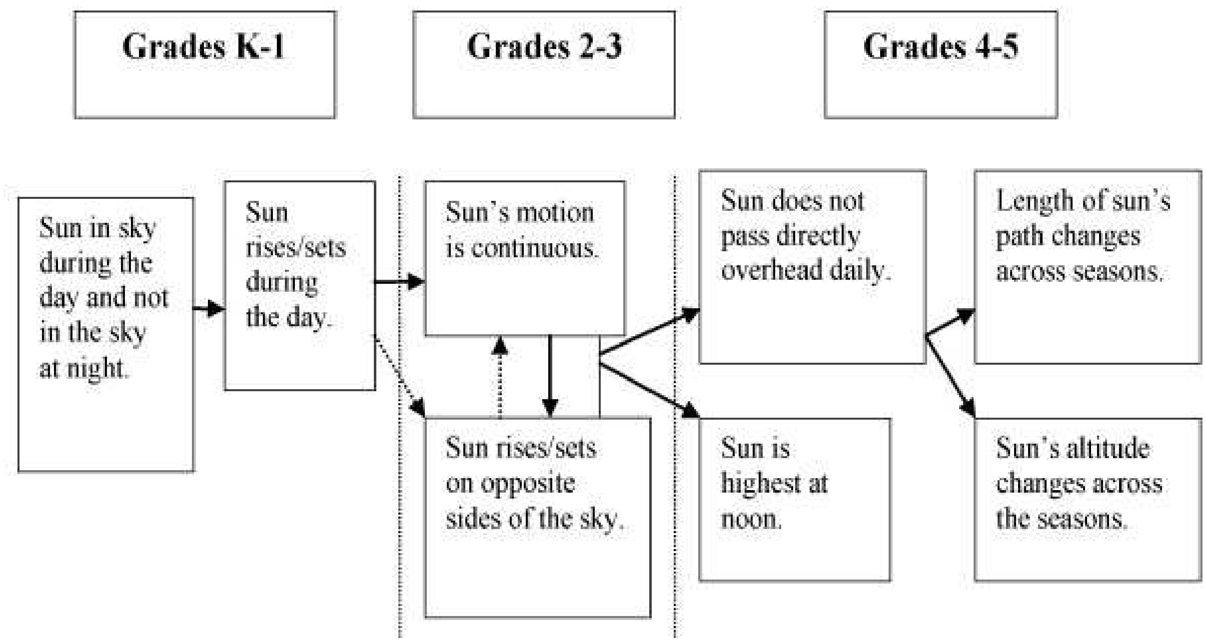

Figure 1. Learning progression for Big Idea 1A: The Sun's path is a smooth arc across the sky that slowly changes in length and altitude across the seasons.

The results of my interviews with first- and third-grade students suggest that after developing the concept that the Sun appears to rise and set, children learn one of two different aspects of the Sun's apparent motion: the Sun's motion appears continuous, or the Sun rises and sets on the opposite side of the sky. Learning one concept (the Sun moves continuously) does not seem to depend on learning the other (the Sun moves across the sky). In first grade, the majority of the children did not demonstrate that the Sun moves continuously across the sky, though some knew that the Sun rises and sets on opposite sides of the sky. The third-grade students I interviewed knew that the Sun does not remain unmoving at the top of the sky, although a large fraction of children were unaware that the Sun moves across the sky to set on the opposite horizon. This may be due to a lack of experience in observing the location of sunrise and sunset, or because children are still developing their spatial orientation abilities (Roberts & Aman 1993). Seventy percent of the third-grade students demonstrated a path for the Sun that crossed the sky and was continuous, supporting the placement of this concept at the second level of the learning progression. The results of Study B support this step in the progression as well; first- and second-grade students showed significant improvement in their ability to describe these concepts after attending the planetarium program. Further information on the development of this learning progression is forthcoming (Plummer & Krajcik 2008).

6. CONCLUSIONS

The results of these studies demonstrate that without quality instruction, children will not develop the scientific understanding of the patterns of apparent celestial motion. Their ideas do tend to develop in some predictable ways, allowing us to create a tentative learning progression for these concepts. The planetarium instruction designed for this study was used to test how children's ideas develop with targeted instruction and supports the placements of concepts along these trajectories. Further, young children are capable of learning to describe these patterns of celestial motion through planetarium instruction. This may allow for future partnerships between classroom instruction and planetarium field trips, resulting in improved depth of understanding of astronomy concepts. More research is needed to test the assumptions of the learning progression developed in this dissertation, including instruction on apparent celestial motion in other environments, as well as instruction that helps children learn to connect their developing understanding of apparent motion to the actual motions of the Earth and Moon.

ACKNOWLEDGMENTS

This work was completed in partial fulfillment of the doctor of philosophy granted by the University of Michigan. I wish to thank my dissertation committee, Dr. Joseph Krajcik (co-chair), Dr. Mario Mateo (co-chair), Dr. Scott Paris, and Matthew Linke, as well as Molly Yunker for assistance in coding the interviews.

References

Adams, J., & Slater, T. 2000, "Astronomy in the National Science Education Standards," *Journal of Geoscience Education*, 48, 39.

Agan, L., & Sneider, C. 2003, "Learning about the Earth's Shape and Gravity: A Guide for Teachers and Curriculum Developers," *Astronomy Education Review*, 2(2), 90. http://aer.noao.edu/cgi-bin/article.pl?id=65.

American Association for the Advancement of Science. 1989, *Science for All Americans*, New York: Oxford University Press.

American Association for the Advancement of Science. 1993, *Benchmarks for Science Literacy*, New York: Oxford University Press.

Atwood, R. K., & Atwood, V. A. 1996, "Preservice Elementary Teachers' Conceptions of the Causes of Seasons," *Journal of Research in Science Teaching*, 33(5), 553.

Bailey, J. M., & Slater, T. F. 2003, "A Review of Astronomy Education Research," *Astronomy Education Review*, 2(2), 20. http://aer.noao.edu/cgi-bin/article.pl?id=63.

Barnett, M., & Morran, J. 2002, "Addressing Children's Alternative Frameworks of the Moon's Phases and Eclipses," *International Journal of Science Education*, 24(8), 859.

Baxter, J. 1989, "Children's Understanding of Familiar Astronomical Events," *International Journal of Science Education*, 11(Special Issue), 502.

Bishop, J. E. 1980, "The Development and Testing of a Participatory Planetarium Unit Emphasizing Projective Astronomy Concepts and Utilizing the Karplus Learning Cycle, Student Model Manipulation, and Student Drawing with Eighth Grade Students," PhD dissertation, The University of Akron, Akron, OH.

Bryce, T. G. K., & Blown, E. J. 2006, "Cultural Mediation of Children's Cosmologies: A Longitudinal Study of the Astronomy Concepts of Chinese and New Zealand Children,"*International Journal of Science Education*, 28(10), 1113.

Diakidoy, I., Vosniadou, S., & Hawks, J. 1997, "Conceptual Change in Astronomy: Models of the Earth and of the Day/Night Cycle in American-Indian Children," *European Journal of Psychology of Education*, 12(2), 159.

Diakidoy, I.-A. N., & Kendeou, P. 2001, "Facilitating Conceptual Change in Astronomy: a Comparison of the Effectiveness of Two Instructional Approaches," *Learning and Instruction*, 11, 1.

Druyan, S. 1997, "Effect of the Kinesthetic Conflict on Promoting Scientific Reasoning," *Journal of Research in Science Teaching*, 34(10), 1083.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. 2007, *Taking Science to School Learning and Teaching Science in Grades K–8,* Washington, DC: National Academies Press.

Fletcher, J. K. 1980, "Traditional Planetarium Programming Versus Participatory Planetarium Programming," *School Science and Mathematics*, 80(3), 27.

Jones, G., Minogue, J., Tretter, T., Negishi, A., & Taylor, R. 2006, "Haptic Augmentation of Science Instruction: Does Touch Matter?" *Science Education*, 90, 111.

Kavanagh, C., Agan, L., & Sneider, C. 2005, "Learning about Phases of the Moon and Eclipses: A Guide for Teachers and Curriculum Developers," *Astronomy Education Review*, 4(1), 34. http://aer.noao.edu/cgi-bin/article.pl?id=138.

Klein, C. A. 1982, "Children's Concepts of the Earth and the Sun: A Cross-Cultural Study," *Science Education*, 65(1), 95.

Mallon, G. L., & Bruce, M. H. 1982, "Student Achievement and Attitudes in Astronomy: An Experimental Comparison of Two Planetarium Programs," *Journal of Research in Science Teaching*, 19(1), 53.

Mant, J., & Summers, M. 1993, "Some Primary-School Teachers' Understanding of Earth's Place in the Universe," *Research Papers in Education*, 8(1), 101.

National Research Council. 1996, *National Science Education Standards*, Washington, DC: National Academy Press.

Nussbaum, J. 1979, "Children's Conceptions of the Earth as a Cosmic Body: A Cross-Age Study," *Science Education*, 63(1), 83.

Nussbaum, J. 1986, "Students' Perception of Astronomical Concepts," *Proceedings of the GIREP Conference—COSMOS—an Educational Challenge, Copenhagen, 18-23 August, 1986*, Copenhagen, Denmark: ESA Publications Division.

Nussbaum, J., & Novak, J. D. 1976, "An Assessment of Children's Concepts of the Earth Utilizing Structured Interviews," *Science Education*, 60(4), 535.

Paivio, A. 1986, *Mental Representation: A Dual-Coding Approach*, Oxford: Oxford University Press.

Plummer, J. D. 2008a, "A Cross-Age Study of Children's Knowledge of Apparent Celestial Motion," *International Journal of Science Education*, in press.

Plummer, J. D. 2008b, "Early Elementary Students' Development of Astronomy Concepts in the Planetarium," unpublished manuscript, submitted for publication.

Plummer, J. D., & Krajcik, J. S. 2008, "A Learning Progression for Apparent Celestial Motion," paper presented at the annual meeting of the National Association for Research in Science Teaching, Baltimore, MD.

Roberts, R., & Aman, C. 1993, "Developmental Differences in Giving Directions: Spatial Frames of Reference and Mental Rotation," *Child Development*, 64(4), 1258.

Samarapungavan, A., Vosniadou, S., & Brewer, W. F. 1996, "Thinking about the Earth, Sun, and Moon: Indian Children's Cosmologies," *Cognitive Development*, 11, 491.

Sharp, J. G. 1996, "Children's Astronomical Beliefs: A Preliminary Study of Year 6 Children in South-West England," *International Journal of Science Education*, 18(6), 685.

Siegal, M., Butterworth, G., & Newcombe, P. A. 2004, "Culture and Children's Cosmology," *Developmental Science*, 7(3), 308.

Smith, C. L., Wiser, M., Anderson, C. W., & Krajcik, J. 2006, "Implications of Research on Children's Learning for Standards and Assessment: A Proposed Learning Progression for Matter and the Atomic Molecular Theory," *Measurement: Interdisciplinary Research and Perspectives*, 4(1), 1.

Sneider, C. I., & Ohadi, M. M. 1998, "Unraveling Students' Misconceptions about the Earth's Shape and Gravity," *Science Education*, 82, 265.

Sneider, C., & Pulos, S. 1983, "Children's Cosmographies: Understanding the Earth's Shape and Gravity," *Science Education*, 67(2), 205.

Stahly, L. L., Krockover, G. H., & Shepardson, D. P. 1999, "Third Grade Students' Ideas about the Lunar Phases," *Journal of Research in Science Teaching*, 36(2), 159.

Trumper, R. 2006, "Teaching Future Teachers Basic Astronomy Concepts—At a Time of Reform in Science Education," *Journal of Research in Science Teaching*, 43(9), 875.

Trundle, K. C., Atwood, R. K., & Christopher, J. E. 2007, "Fourth-Grade Elementary Students' Conceptions of Standards-Based Lunar Concepts," *International Journal of Science Education*, 29(5), 595.

Vosniadou, S., & Brewer, W. F. 1992, "Mental Models of the Earth: A Study of Conceptual Change in Childhood," *Cognitive Psychology*, 24, 535.

Vosniadou, S., & Brewer, W. F. 1994, "Mental Models of the Day/Night Cycle," *Cognitive Science*, 18, 123.

ÆR
139 - 148