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Learning About the Earth's Shape and Gravity: A Guide for Teachers and Curriculum Developers

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Abstract

The scientific model of the Earth in space--consisting of the spherical Earth and gravity concepts--is one of the first models that children encounter in their science classes. Children's understanding of these concepts is essential for further conceptual development in astronomy. This article provides a thorough review of educational research concerning children's development of Earth shape and gravity concepts in the context of national standards and the history of science. Based on this review, the authors recommend instructional approaches at appropriate grade levels to enable students to fully grasp these fundamental concepts.

1. INTRODUCTION

NASA Headquarters, Washington D.C., Release 03-114, March 24, 2003:

NASA and Pearson Scott Foresman (PSF), the leading pre-K-6 educational publisher, will formally announce an agreement on Thursday, March 27 at 10:00 a.m. EST at Overbrook Elementary School in Philadelphia. The goal of the partnership is to create a multi-faceted project to spark student imagination, encourage interest in space exploration, and enhance elementary science curricula.

Under the terms of the special relationship, PSF editors and authors will draw upon NASA's rich archival material and extensive research in biological, physical, Earth and space sciences to create the Scott Foresman Science series for elementary levels. NASA experts will review the content, and PSF will ensure the curricula reflects the National Science Education Standards, Project 2061 Benchmarks, and specific, targeted state standards. (NASA, "NASA Teams" 2003)

One of NASA's primary goals, reflected in various documents and speeches by its current director, Sean O'Keefe, is to "Inspire the next generation of explorers . . . as only NASA can" (NASA Office of Space Science 2003, p. v). The relationship between NASA and a commercial publisher, announced in the above press release, has great potential in achieving that goal. The publisher will rely on NASA scientists to ensure that its textbooks are accurate, while NASA leaders can rely on Pearson's capacity to reach into classrooms with richly illustrated standards-based curriculum materials.

Although the authors of this article applaud this collaboration, we feel that it is also important to take into account the results of educational research so that the textbooks are not only engaging, standards-based, and scientifically accurate but also educationally effective.

Applying educational research to the development of textbooks is not necessarily a straightforward process. Although research reviews are valuable, they do not necessarily place the research into a context that will help curriculum developers and teachers. The purpose of the present article is to do so. It is addressed to teachers and curriculum developers interested in teaching students in elementary and middle school about the Solar System, including the team of NASA researchers and PSF writers and editors who will create the Scott Foresman Science series.

In order to keep the length of the present article manageable and to do justice to the research studies, we have limited the scope to students' understanding of the scientific model of the Earth as a spherical body in space, and the related concept of gravity that explains how people can live all around the planet. This model is one of the first that children encounter in their school science classes, and it is a crucial stepping stone for understanding various phenomena, such as night and day, Moon phases, and seasons. Without a solid grasp of the spherical Earth model, students will have difficulty understanding what it means to launch a space satellite or to send a probe to Mars or one of Jupiter's moons.

The primary goal of this article, then, is to report on the educational research concerning the topic of the Earth's shape and gravity and to recommend instruction based on the findings of this research. The research concerning this topic is well developed, with multiple research designs and interpretations of data based on various theories of learning. In fact, this topic is arguably the most thoroughly studied in the entire field of astronomy education. In our view, it is crucial that educators and curriculum developers use this body of research when considering appropriate instruction in astronomy.

The article is divided into five sections: (a) introduction, (b) historical development of the spherical Earth concept, (c) current educational standards and recommendations concerning the concepts of the Earth's shape and gravity, (d) a summary of educational research on how students' understanding of these concepts evolves during the elementary and middle school grades, and (e) recommendations for how and when the spherical Earth model should be presented in the K-6 curriculum.

Section four includes particular attention to a study by Sneider and Ohadi (1998) that combines instruction with educational research in a format that we refer to as action research (Christenson et al. 2002; Dick 1999). Section five synthesizes the findings of educational researchers concerning this topic and addresses the following questions:

- What are the important components of the spherical Earth concept?
- How will we know if children understand it?
- Is children's knowledge organized in the form of personal theories, or is their knowledge fragmentary?
- Is it important for students to express their current understanding of the concept as a step toward learning?
- At what age level is it appropriate to introduce the spherical Earth concept in its fullest form?

2. GENESIS OF THE SPHERICAL EARTH CONCEPT

Some of the earliest historical records of ancient civilizations portray flat Earth models of the universe. Many historical summaries and textbooks recount the colorful cosmologies of Babylonia, Egypt, and China, the great civilizations that flourished some three to four thousand years ago. These early visions of the universe were populated by gods and goddesses and offered explanations for how the Sun manages to travel from where it sets in the west to where it rises in the east. According to the cosmology of later Babylonia, for example, Earth and sky are supported by a vast ocean. Above the sky are the upper waters, and above that is the dwelling place of the gods, which the Sun enters through a door at dusk and emerges through a different door at dawn. Perhaps more widely known is the Egyptian vision of the Sun god Ra being carried through the sky in a boat, which enters another world at night. In some Egyptian stories, the Sun is extinguished at night and an entirely new Sun is born every morning (Dreyer 1953).

The first records of the spherical Earth concept that have survived originated in ancient Greece. Most of what we know about the early ideas and conclusions of the early Greek philosophers comes from the writings of Aristotle (384-322 B.C.E.). Aristotle's writings and fragments from other authors have been analyzed and summarized by many historians of science (e.g., Lloyd 1970; Toulmin & Goodfield 1961; Dreyer 1953). The story is briefly summarized as follows.

In *On the Heavens*, Aristotle used logic to dispense with a number of erroneous ideas about the Earth proposed by philosophers of previous centuries, such as the idea of Thales (fl. 585 B.C.E.)--that the Earth floats like a cork on water. Instead, Aristotle defended the idea that the Earth is a sphere, which had been proposed at least two centuries earlier. Although it is not known for certain whether the spherical shape of the Earth was first proposed by Pythagoras or Parmenides (Dreyer 1953, 20), we do know that Aristotle defended the idea with a number of arguments typically heard in today's classrooms: The shape of the Earth's shadow on the Moon during a lunar eclipse is curved; a journey to the south reveals certain stars in the night sky that cannot be seen at all further to the north; and different stars pass directly overhead in different north-south locations (Aristotle 1971, 247-255).

Aristotle not only showed that the spherical Earth concept was supported by evidence of observed phenomena but also argued that it must be so because the idea was consistent with his ideas about matter and motion (described in his book *On Physics*). In Aristotle's view, the center of the Earth corresponds to the center of the universe. The natural motion of all Earthy matter is toward the center of the universe, where it gathers into a sphere. Liquids, being less heavy, layer on top of the Earth, while aery and fiery matter move away from the center. Each object's natural position is determined by its composition, the proportion of each of these four elements. In Aristotle's physics, it is not difficult to understand how people can live all around the world. Because they are composed largely of Earthy and liquid elements, they tend to move down, toward the center of the Earth.

Although Aristotle's theory for why people do not fall off the "bottom" of the spherical Earth is considered erroneous by today's standards, it did provide a rationale for the spherical Earth concept that was widely known and accepted by educated people for more than two thousand years, until Newton published his theory of universal gravitation in the 18th century.

Perhaps the most remarkable measurement of ancient times was the determination of the Earth's circumference by Eratosthenes (276-194 B.C.E.), librarian in the great library at Alexandria. Eratosthenes learned that in Syene, some distance to the south, no shadows were cast by vertical objects on the longest day of the year, so the summer solstice Sun must be directly overhead. On that date in Alexandria, the Sun cast a shadow that was 1/50th of the height of the object. From a simple geometrical argument, he realized that it must mean that Alexandria and Syene were 1/50th of the Earth's circumference apart. When that distance was measured, the distance was multiplied by 50 to determine the circumference of the Earth. Although there is some uncertainty about the actual length of the units used at that time, historians believe that the measured value was quite close to the modern determination of 25,000 miles (Kuhn 1957, p. 274-275).

Many people are under the impression that, in the time of Columbus, most people believed the Earth to be flat. That erroneous idea can be traced to an influential biography of Columbus by Washington Irving (1981, p. 49-50), who probably fabricated the idea for dramatic effect. In fact, the argument between Columbus and Queen Isabella's counselors was about the size of the Earth and the extent of the Eurasian land mass. Columbus argued that the Earth is quite small, and that the land distance between Europe and Cipangu (Japan) is quite large, so the distance across the "Ocean Sea" would be short enough to cross with the amount of stores that a ship could carry. In fact, the Queen's counselors were right. If Columbus and his crew had not run into the Americas, they would have had to turn back or perish at sea long before reaching their destination (Nunn 1924).

It's also helpful to keep in mind that neither Columbus nor the Queen's counselors thought about the Earth exactly as we do. Aristotle's physics still held sway. The Earth was thought to be the center of the universe. It was unmoving because it had no reason to move from its natural resting place. The "planets" (which included the Sun and Moon) were made of something completely different from Earthly materials. They were composed of quintessence, which neither fell nor rose but spun in perpetual circles far above the clouds. Although Columbus's able seamen observed the changing shadows of vertical sticks during the day, they explained the movement in terms of the Sun's motion around the Earth rather than rotation of the Earth on its axis. It was not until 1543, more than 50 years after Columbus sailed the ocean blue, that the world heard the strange ideas of Copernicus: that the sun, not the Earth, is at the center of the universe, and night and day are caused by the spinning of the world that seems so solid and motionless beneath our feet.

In order to gain acceptance for his ideas about the motion of the Earth, Copernicus was obliged to modify Aristotle's physics. To explain why the Earth did not immediately rush to the center of the Sun, Copernicus envisioned several centers--one for the Earth and one for each of the other planets--toward which the various parts of the body tended to move. He used a Latin term translated as "gravity" to refer to this natural tendency, and the term "center of gravity" to refer to the centers in each of the planets (Kuhn 1957). It was not until Sir Isaac Newton formulated his law of universal gravitation more than 200 years later that modern ideas about the shape of the Earth and gravity took on their modern form.

Given this review of the historical development of the Earth's shape and gravity concepts, we turn now to the recommendations of the National Research Council concerning what students at various ages should be learning about these concepts. We will also look briefly at the current curriculum of the Scott Foresman Science series as it addresses these topics.

3. WHAT THE STANDARDS RECOMMEND

The National Science Education Standards (NSES; National Research Council 1996) recommends that in the early elementary grades, children be given many opportunities to observe and learn from the world around them. However, educators are warned that students of this age are not yet ready to explain what they see in terms of models. This idea is explicitly related to the Earth's spherical shape as follows:

> By observing the day and night sky regularly, children in grades K-4 will learn to identify sequences of changes and to look for patterns in these changes. As they observe changes, such as the movement of an object's shadow during the course of a day, and the positions of the sun and the moon, they will find the patterns in these movements. They can draw the moon's shape for each evening on a calendar and then determine the pattern in the shapes over several weeks. These understandings should be confined to observations, descriptions, and finding patterns. Attempting to extend this understanding into explanations using models will be limited by the inability of young children to understand that Earth is approximately spherical. They also have little understanding of gravity and usually have misconceptions about the properties of light that allow us to see objects such as the moon." (National Research Council 1996, p. 130, 134)

According to the NSES, the spherical Earth concept is accessible to children in grades five through eight, and experiences involving direct observation and satellite data can be used to help them understand this concept: "The understanding that students gain from their observations in grades K-4 provides the motivation and the basis from which they can begin to construct a model that explains the visual and physical relationships among Earth, sun, moon, and the solar system. Direct observation and satellite data allow students to conclude that Earth is a moving, spherical planet, having unique features that distinguish it from other planets in the solar system" (National Research Council, p. 159), and that ". . . Gravity alone holds us to the Earth's surface and explains the phenomena of the tides" (p. 160-161).

In summary, the National Science Education Standards recommend that students in grades K-4 have opportunities to make systematic observations of the world and recognize patterns in the data, but not be asked to interpret that data in terms of models--and especially not in terms of models such as the spherical Earth concept--that are difficult for young children to understand. That recommendation is counter to the approach of many textbooks that take some pains to explain, at the first- or second-grade level, that the Earth is spherical in shape and that we experience day and night because the spherical Earth turns on its axis.

The Scott Foresman Science series (Cooney et al. 2003) for grades one through six discusses the concept of gravity in physical science units and the shape of the Earth in Earth science units, so the Earth's shape and gravity are not generally discussed together. With regard to the Earth's shape, the series introduces the idea that the Earth is shaped like a ball, surrounded by air, in the first grade. In grade two, students learn that the day-night cycle is caused by the ball-shaped Earth (represented by a globe) spinning on its axis. In grade three, students are introduced to a model of the Solar System in which the Earth and other planets are ball shaped. In grade four, students use a globe and flashlight to explore the causes of seasons. In grade five, students make a model of the Solar System. They are shown Ptolemy's Earth-centered model of the Solar System compared with the modern Sun-centered model, and learn more about planets and other Solar System objects. In grade six, students review the model of the Solar System, this time using the word "spherical" to refer to the Earth and other planets.

The Scott Foresman Science series introduces gravity in grade two as "the force that pulls things down" (Cooney et al. 2003, Grade 2 p. B48). In grade three, students are taught that the pull of the Moon's gravity is the main cause of tides on Earth. In grade four, students are instructed that gravity keeps Earth in its orbit around the Sun. In grade five, students study gravity with respect to the distinction between mass and weight, dependence on distance, projectile motion, and acceleration. In grade six, students are taught about Newton's three laws of motion, then go on to study stars, galaxies, and the expanding universe.

In summary, the Scott Foresman Science curriculum series refers to the spherical Earth concept every year from grade one through grade six. However, with the exception of explaining the day-night cycle, students are never asked to explore the implications of this concept from the viewpoint of a person who lives on the Earth, or to consider how the Earth's spherical shape is related to gravity. Additional concepts, such as explanations for seasons and models of the Solar System, are introduced with the assumption that students fully understand the spherical Earth concept presented in grade one. Which approach is correct? Should the spherical Earth and gravity concepts be moved from the first- and second-grade level as it is presented in the current Scott Foresman Science series to the fifth- to eighth-grade level as recommended by the NSES? If so, where in that range should it go? And how should it be taught and assessed? For answers to these questions, we turn to a detailed review of the educational research on this topic.

4. LITERATURE REVIEW

One of the most influential psychologists of the 20th century was Jean Piaget. His method for questioning children, known as the clinical interview, has provided generations of researchers with a rich and subtle instrument for exploring young minds. In the introduction to *The Child's Conception of the World* (1929), he argues that the clinical interview uses a combination of observation, testing, and interview questions that should be determined by "the spontaneous questions actually asked by children of the same age or younger" (p. 5). In this text, he recounts a study in which he observed that when questioned, children readily invent their own theories of the world, and that these theories go through stages as children mature. When he asked children ages 6, 7, and 8 where the Sun and Moon came from, most indicated their belief that these bodies were alive, and that they were born and grow like people and animals. Older children, ages 10 and 11, thought that the Sun and Moon arose from natural causes, while those in between revealed a mixture of both animate and natural causes.

Later researchers were less interested in children's ideas about the origin of celestial bodies than in their understanding of key concepts in the school curriculum: the Earth's spherical shape and gravity. So many studies have been conducted on these two interrelated concepts that we have divided the review into four sections: (a) seminal research, (b) expansion and elaboration of the research base, (c) challenges to previous research, and (d) action research in the classroom. Table 1 presents a summary of each study that is reviewed in this paper.

Table 1. Summary of Research

Authors & Title (Chronological)	**Method & Sample**	**Results**
Nussbaum, J., & Novak, J. (1976). An Assessment of Children's Concepts of the Earth Utilizing Structured Interviews.	Action Research: Assess effectiveness of audio-tutorial instruction program SAMPLE: 26 grade 2: experimental group; 26 grade 2: control group (USA) METHOD: Interview and props (globe)	Instruction had no significant impact on student performance. Identification of five notions.
Nussbaum, J. (1979). Children's Conception of the Earth as a Cosmic Body: A Cross Age Study.	SAMPLE: 240 grades 4-8 (Israel) METHOD: Multiple-choice questionnaire and props	Five notions found among children in grades 4-8, with older children generally at higher levels
Mali, G. B., & Howe, A. (1979). Development of Earth and Gravity Concepts among Nepali Children.	SAMPLE: 250 8-, 10-, & 12-year-olds, rural and urban (Nepal) METHOD: Interview and props	Identified Nussbaum's five notions, progression to scientific model with age, lower performance of rural group
Klein, C. (1982). Children's concepts of the earth and the sun: A cross-cultural study.	SAMPLE: 24 grade 2, Mexican American & European American METHOD: Interview and props	Identified Nussbaum's five notions, no difference between cultural groups
Sneider, C., & Pulos, S. (1983). Children's Cosmographies: Understanding the Earth's Shape and Gravity.	SAMPLE: 159 grades 3-8 (USA) METHOD: Interview and props	Identified Nussbaum's five notions, developmental scale for Earth's shape and gravity correlated to notions

Nussbaum, J., & Sharoni-Dagan, N. (1983). Changes in Second Grade Children's Preconceptions About the Earth as a Cosmic Body Resulting from a Short Series of Audio-Tutorial Lessons.	Action Research: Assess improved instructional program SAMPLE: 114 grade 2 (Israel) METHOD: Interview, multiple-choice questionnaire and props	Minimal gains in student performance with instruction; identified Nussbaum's five notions
Vosniadou, S., & Brewer, W. (1992). Mental Models of the Earth: A Study of Conceptual Change in Childhood.	SAMPLE: 20 grade 1, 20 grade 3, 20 grade 5 (USA) METHOD: Interview	Identification of mental models: initial, synthetic, and scientific; progression to scientific model with age
Vosniadou, S., & Brewer, W. (1994). Mental Models of the Day/Night Cycle.	SAMPLE: 20 grade 1, 20 grade 3, 20 grade 5 (USA) METHOD: Interview	Identified high correlation between mental models of the Earth and the day-night cycle
Samarapungavan, A., Vosniadou, S., & Brewer, W. (1996). Mental Models of the Earth, Sun, and Moon: Indian Children's Cosmologies.	SAMPLE: 19 grade 1, 19 grade 3 (India) METHOD: Interview and props (creation of clay models)	Identified progression to scientific model with age, difference in synthetic models attributed to cultural groups and methodological differences (clay models)
Sneider, C., & Ohadi, M. (1998). Unraveling Students' Misconceptions about the Earth's Shape and Gravity.	Action Research: Assess effectiveness of instructional program SAMPLE: 539 grades 4-9 experimental and control groups (USA) METHOD: Questionnaire	Identified significant gains in student performance with instruction, especially at grades 4-5
Schoultz, J., Saljo, R., & Wyndhamn, J. (2001). Heavenly Talk: Discourse, Artifacts, and Children's Understanding of Elementary Astronomy.	SAMPLE: 8 grade 1; 8 grade 3; 9 grade 5 (Sweden) METHOD: Interview and props (globe)	Identified high performance throughout study; little evidence for Nussbaum's early notions

Butterworth, G. Siegal, M. Newcombe, P. A., & Dorfman, M. (2002). Models and Methodology in Children's Cosmology.	SAMPLE: Study 1: 59 Australian, 79 English; ages 4-5, 6-7, 8-9 Study 2: 45 Australian; age 5: Compare questionnaire to interview protocol METHOD: forced-choice interview and props (globe)	Identified high performance throughout study; higher performance among Australian students, and higher performance using authors' protocol than V&B's protocol
Nobes, G., Moore, D. G., Martin, A. E., Clifford, B. R., Butterworth, G., Panagiotaki, G., & Siegal, M. (2003). Children's Understanding of the Earth in a Multicultural Community: Mental Models or Fragments of Knowledge?	SAMPLE: 85 European British, 82 Gujarati British; ages 4-5, 6-7, 8 METHOD: forced-choice interview and props (globe)	Identified high performance throughout study; responses identified as fragmented through statistical analysis

4.1 Seminal Research

Nussbaum & Novak (1976) used clinical interviews to test the effectiveness of a lesson about the Earth's spherical shape and gravity for second graders. The students were shown a carefully designed audio-tutorial program about these concepts. Instruction consisted of slides with a taped narration. Using a globe as a model of the Earth, the children observed people living all around the ball-shaped Earth. They saw how the appearance of the Earth changes as one moves away from it in a rocket ship. This was dramatized with 3-D slides. Students also saw images of the Earth taken by astronauts in space. Finally, they learned about how gravity pulls objects toward Earth's center, holding people on the Earth.

Clinical interviews were used to compare 26 children who participated in the lesson with a comparable group of 26 children who did not. The interviews began with questions about the Earth's shape and how things would fall at different points on a model of the Earth. The children were also asked to explain their answers. The researchers were disappointed to find no significant difference between the students who experienced the audio-tutorial lesson and those who received no instruction. However, in an effort to characterize the students' understanding, the researchers identified five levels of understanding, which they called "notions," about the Earth's shape and gravity. Although the teaching experiment resulted in very little learning, the findings about children's understanding of these concepts were striking and easily replicated in further studies. Consequently, the 1976 Nussbaum and Novak paper is now recognized as a major milestone in astronomy education research.

A cross-age study by Nussbaum (1979a), based on interviews with 240 children in grades four through eight, enabled the author to refine the five notions found in the earlier study and to learn how children's understanding evolves as they mature and are exposed to more information about the Earth and gravity in school. The interview protocol made use of drawings, Earth globes, and other props. The five notions, as refined in the 1979 study, are briefly described below and illustrated in Figure 1.

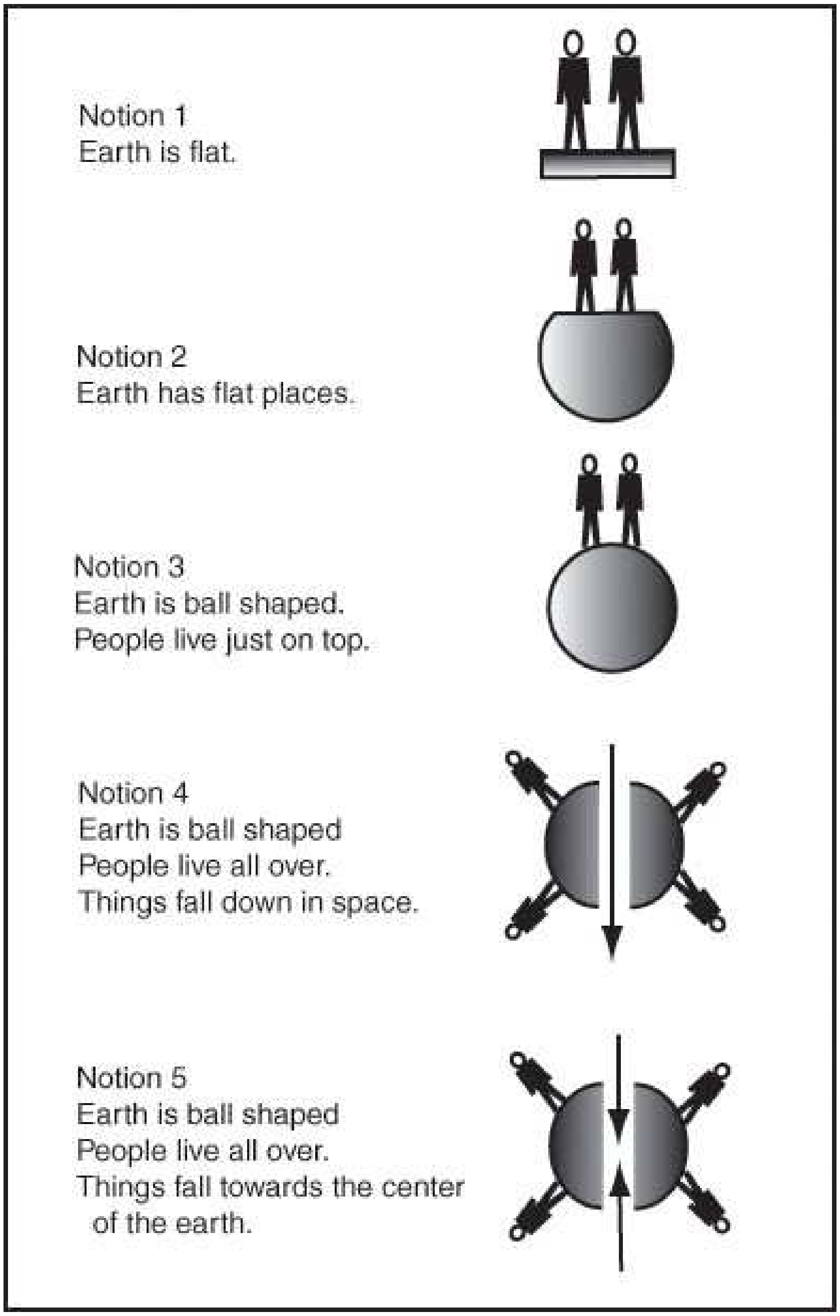


Figure 1. Earth notions from Nussbaum & Novak, 1976.

Notion 1. Many of these children initially answered the question, "What is the shape of the Earth?" by saying "round." If the interview had stopped at this point, the child would have been classified as understanding the spherical Earth concept. However, when asked, "Which way do you look to see the Earth?" some of the children said that the round Earth is "up in the sky where the astronauts go," and that the Earth beneath our feet is, of course, quite flat. In explaining what she meant by a "round Earth," another child explained that the Earth is a flat round island surrounded by a big ocean. Columbus proved that the Earth is round by sailing all the way around the island.

Notion 2. A child whose idea of the Earth was classified as notion 2 explained that the Earth is "round like a ball, but people live on the flat part in the middle." Some children said that the upper part of the ball is the sky, and the lower part is the ground. The Sun, Moon, and stars are, in some cases, envisioned as being inside the sky, on its surface, or above the sky. This notion, in which the children combined their earlier ideas with the concept of a globe, is more advanced than notion 1 because it includes the idea that the Earth we live on is spherical in shape and is surrounded by space.

Notion 3. These children understand that the Earth we live on is spherical in shape and surrounded by space. They also understand that people live on the surface of the Earth. However, they believe that people cannot live on the "bottom" of the Earth, because they would fall off.

Notion 4. Children who hold this notion understand that the planet we live on is shaped like a ball, and that people live all over the Earth because gravity holds them down on the surface. However, when asked what would happen to objects dropped into tunnels inside the Earth, they revert to the idea that there is an absolute "down" direction in space.

Notion 5. The "down" direction is related to the center of the Earth, so people can live all around the Earth's surface, and objects dropped into tunnels would fall toward the center of the Earth.

The results showed a wide variety of notions at each grade level. As might be expected, older students tended to hold higher level notions than younger students. However, even among the eighth graders in the study, only about 25% expressed a full understanding of the spherical Earth in space, with objects falling toward the center of the Earth. Although it was not possible to determine the path of individual development, the distribution of notions with age suggested that children's ideas develop through a sequence from a flat Earth concept to a mixture of earlier ideas with what they learn in school to eventual understanding of the scientific model.

A further study by Nussbaum & Sharoni-Dagan (1983) involved modifying the audio-tutorial lesson described in the 1976 study based on the findings of the 1979 cross-age study. The new lesson emphasized the idea that there is space all around the Earth and that gravity pulls everything on the Earth's surface toward the center. Subjects included three comparable groups of second graders in Israel, 114 subjects in all. Two classes received the lesson. Students in one class were interviewed before and after instruction. To eliminate the effects of the preinterview, students in the second class were interviewed only after the lesson. Students in the third class were interviewed but did not receive any instruction. In the class that was pre- and postinterviewed, about 50% of the children showed some increase in understanding, most by only one notion. Before instruction, none of the students was at notion 5, whereas after instruction, about 15% of the students were found to be at the highest level. Postinterviews of the students in the second class that received instruction were slightly higher than postinterviews from the first class, although most remained at notion levels 1, 2, or 3. Results from interviews of students in the control class were similar to those of the preinterviews of the experimental class. The authors concluded that the experimental lesson made only a modest contribution to the learning of these concepts.

In summary, the work of Joseph Nussbaum and his collaborators in the late 1970s and early 1980s established that teachers of grades two through eight are likely to have a class of students with a broad range of ideas about the Earth’s shape and gravity. Nussbaum and his colleagues conducted two experiments to teach the spherical Earth concept to second graders, with limited success. Perhaps most important is that these studies established a scheme for classifying children’s levels of understanding into five notions.

4.2 Expansion and Elaboration of the Research Base

Mali & Howe (1979) used the interview protocol and props developed by Nussbaum in a study of 250 rural and urban children ages 8, 10, and 12 in Nepal. The researchers found that "The notions about Earth held by Nepali children are remarkably similar to the notions held by Americans and Israeli children." They also found that the number of children who hold notions more in keeping with the current scientific model increases with age, but that Nepali children, who are exposed to less schooling than Americans and Israelis, develop the concepts more slowly. They also found that conceptual development was somewhat more rapid in urban children than in rural children, and that there were no differences between boys and girls, or differences attributable to occupation of parents or opportunities to travel and learn other languages.

Similar results were found by Klein (1982), although the sample size was quite small: 24 second graders, including 12 Mexican American children and 12 European American children, in St. Paul, Minnesota. Although all of the children had studied the Earth’s spherical shape, gravity, and the cause of day and night in school, very few understood these concepts. There were no significant differences between boys and girls or between the two cultural groups, except that more of the Mexican American children exhibited precausal thinking (e.g. the Sun "hid" at night). The author concluded that, "Considering the number of children who did not demonstrate an understanding of the concepts of the Earth and sun that had been taught in grades one and two, additional research is needed to determine if either the concepts are too abstract for the majority of children at this age or if different methods and materials would increase their understanding" (Klein 1982).

The next study was prompted when teachers attending a workshop expressed incredulity that some students as old as middle school did not understand the spherical Earth concept. Three teachers worked with two researchers over the next few months to pilot test the interview protocol and methods of coding the results (Sneider & Pulos 1983). One-hundred fifty-nine children in grades three through eight in the San Francisco Bay Area participated in the study. To the great surprise of the teachers who conducted the interviews, the results were consistent with all of the previous studies: Nussbaum’s five notions were found in all groups at all ages. The investigators also subjected the data to a statistical analysis that established that the five notions formed a developmental scale. The only modification was a finding of a significant number of children (14% of the sample) who were at notion 4, but who nonetheless had difficulty understanding that people live "under our feet" on the other side of the world. In addition to the journal article, the research team published an article in a teachers’ magazine (Sneider, Pulos, Porter, Freenor, & Templeton 1986) that described the research and presented a written version of the questionnaire with a rubric for coding responses. This allowed teachers to assess their own students’ understanding of the Earth’s shape and gravity concepts. Multiple-choice responses reflected actual children’s ideas based on the results of interviews (as described in Sneider & Pulos 1983). The questionnaire and rubric are shown in Figures 2 and 3.

Name ________________________________ Date ____________

WHAT ARE YOUR IDEAS ABOUT THE EARTH?

QUESTION 1: Why is the earth flat in picture #1 and round in picture #2? (Circle the letter in front of the best answer.)


1


2

A. They are different earths.

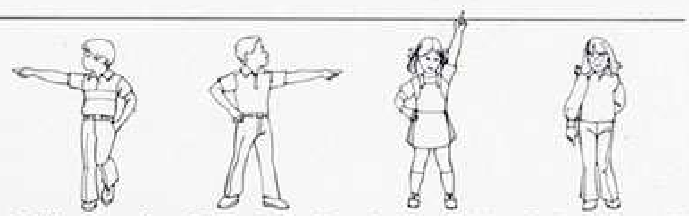
B. The earth is round like a ball, but people live on the flat part in the middle.

C. The earth is round like a ball, but it has flat spots on it.

D. The earth is round like a ball but looks flat because we see only a small part of the ball.

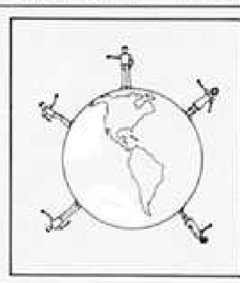
E. The earth is round like a plate or record, so it seems round when you're over it and flat when you're on it.

QUESTION 2: Pretend that the earth is glass and you can look straight through it. **Which way would you look, in a straight line, to see people in far-off countries like China or India?**



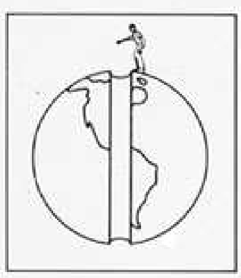
A. Westward? **B.** Eastward? **C.** Upward? **D.** Downward?

QUESTION 3: This drawing shows some enlarged people dropping rocks at various places around the earth. **Show what happens to each rock when it's dropped by drawing a line from the person's hand to where the rock finally stops.**



Explain your answer here.

QUESTION 4: Pretend that Superman dug a tunnel all the way through the earth, from pole to pole. Imagine that a person holds a rock above the opening at the North Pole. **Show what happens to the rock when it's dropped by drawing a line from the person's hand to where the rock finally stops.**

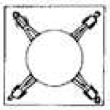
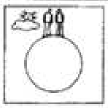


Explain your answer here.

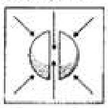
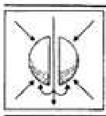
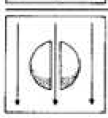
Figure 2. "What Are Your Ideas About the Earths Shape and Gravity?" Questionnaire from Sneider et al. 1986.

Levels of Understanding About the Earth's Shape and Gravity

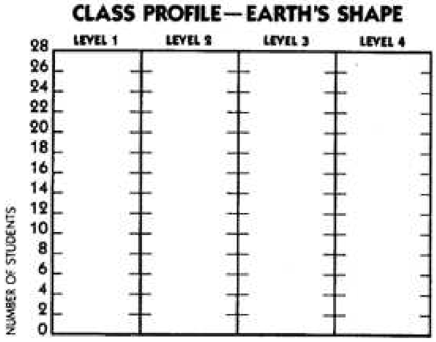
EARTH'S SHAPE

		Definition of each level	How to classify answers	Number of students
	**SHAPE LEVEL 4**	The earth is shaped like a ball, and people live all around the ball.	**QUESTION 1:** Answer D and **QUESTION 2:** Answer D.	
	**SHAPE LEVEL 3**	The earth is shaped like a ball, but people live just on top of the ball.	**QUESTION 1:** Answer D and **QUESTION 2:** Answers A, B, or C.	
	**SHAPE LEVEL 2**	The earth is shaped like a ball, but people live on the flat parts of it (or inside the ball).	**QUESTION 1:** Either answer B or C.	
	**SHAPE LEVEL 1**	The earth is flat.	**QUESTION 1:** Either answer A or E, or no answer at all.	

GRAVITY

		Definition of each level	How to classify answers	Number of students
	**GRAVITY LEVEL 3**	Objects fall toward the *center* of the earth.	**QUESTION 3:** Rocks are shown falling straight down to the surface of the earth, near each figure's feet. **QUESTION 4:** The rock is shown falling to the earth's center, where it stops or falls through the center and bobs up and down between the North/South Poles.	
	**GRAVITY LEVEL 2**	Objects fall toward the *surface* of the earth.	**QUESTION 3:** Rocks are shown falling straight down to the surface of the earth near each figure's feet. **QUESTION 4:** The rocks do *not* end up in the earth's center. (They may be shown passing all the way through the earth, sticking to the earth's surface, or taking some other path.)	
	**GRAVITY LEVEL 1**	Objects fall *down* in space.	**QUESTION 3:** Rocks are *not* shown falling straight down to the surface of the earth. (They may be falling down to the bottom of the page or shooting at some other angle around the planet.)	

CLASS PROFILE—EARTH'S SHAPE



GRAVITY

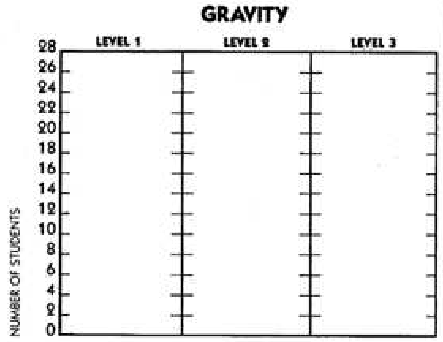


Figure 3. Rubric for coding responses to "What Are Your Ideas About the Earths Shape and Gravity?" from Sneider et al. 1986.

Both empirical and theoretical research on these concepts was considerably advanced with the publication of a series of papers by a team from the University of Illinois and the University of Athens, Greece (Vosniadou 1992, 1994; Vosniadou & Brewer 1987, 1992, 1993, 1994; Samarapungavan, Vosniadou, & Brewer 1996).

In their first published paper on this topic, Vosniadou and Brewer (1987) reviewed various theories for cognitive change, beginning with Piaget's theory of learning. Most learning, in which we do not change our current knowledge, involves the simple addition, or assimilation of new information. Occasionally, however, an encounter with information that conflicts with our current understanding causes fundamental changes, or accommodation, of previous knowledge. The authors noted the relationship of these ideas about cognitive development to Thomas Kuhn's (1962) theory of the development of science. Assimilation corresponds to Kuhn's normal science, when new knowledge is generated but the underlying theories remain the same, while accommodation corresponds to the less frequent scientific revolution, when conflicting discoveries, or new interpretations of data, cause entire communities of scientists to radically shift their fundamental theories. The authors chose to study the change in children's thinking from a flat Earth view to the idea that we live on a ball in space because it exemplifies that radical shift in thinking called accommodation in an individual, and scientific revolution in a community.

In subsequent papers, Vosniadou and Brewer described their investigations, which relied on clinical interviews that made use of two-dimensional drawings and 3-D models, and later, the creation of three-dimensional sculptures using modeling clay (Samarapungavan, Vosniadou, & Brewer 1996). Their findings were consistent with previous work by Nussbaum and others, but rather than using the term "notions" to describe the children's ideas, Vosniadou and Brewer preferred the term "mental models."

The change in terminology is significant. In contrast to the term "notion," which suggests a vague idea, the term "model" implies a deep-seated mental structure that a person uses to reason about the world. Vosniadou and Brewer's interest was in how the models are used in thinking and in how they develop over time.

With regard to how children's mental models of the Earth change over time, Vosniadou and Brewer described three stages. An initial model, based on everyday experience, is characterized by two entrenched ideas that are resistant to change. These ideas, called presuppositions, are that (a) the Earth is flat and (b) things fall down. As children are exposed to scientific knowledge that the Earth is shaped like a sphere, they will attempt to integrate this new information without giving up their presuppositions, thereby forming a new synthesis, or synthetic model, to explain the shape of the Earth. These synthetic models include the "hollow sphere" model (the Earth is a hollow sphere in which we inhabit the flat part in the middle), the "dual Earth" model (the spherical Earth is in space and the flat Earth is underneath us), and the "flattened sphere" model (the Earth is spherical with a flat top and flat bottom; Vosniadou & Brewer 1992). Only when children are able to free themselves of their presuppositions are they able to develop a scientific model of the Earth as a sphere, with gravity pulling things toward the center.

Vosniadou & Brewer (1994) found a high correlation between students' models of the Earth's shape and gravity and their explanations of the day-night cycle. Eighty percent to eighty-five percent of the children in their samples used well-defined mental models in a consistent fashion to answer questions. This result supported their interpretation that mental models are complete theories held by the students, as opposed to the alternative view: that students' knowledge is fragmented or loosely organized. Further, their research supports the findings of previous studies with regard to the age distribution of responses. In one of their earlier studies (1992), the responses of 60 students from grades one, three, and five were classified according to the appropriate models of the Earth. The spherical Earth concept was identified with the most frequency in the fifth grade (60%) and least frequency at grades one (15%) and three (40%). Synthetic models of the Earth were identified at all ages, including the dual Earth model, the hollow sphere model, and the flattened sphere model. Further details on the results of other studies completed by Vosniadou, Brewer, and their colleagues are presented in Table 1.

In summary, the work of Mali & Howe (1979); Klein (1982); Sneider & Pulos (1983); and Vosniadou & Brewer (1987, 1992, 1993, 1994) firmly established the replicability of Nussbaum's seminal work. The five notions identified by Nussbaum were found in all of these studies in various countries and cultures among children ages 8 to 14. Although older children tended to score at a higher level, fewer than half of the eighth graders were at the highest level. Finally, Vosniadou and Brewer put forward a plausible theory to explain the developmental sequence through their description of initial synthetic and scientific models, and marshaled evidence to support their claim that children's mental models are theories that enable them to think in a coherent and systematic way about the world around them.

4.3 Challenges to Previous Research

The series of studies to follow questioned both the research methods and the theoretical framework of the earlier researchers in this field. Schoultz, Saljo, & Wyndhamn (2001) completed the first of these studies. These researchers began by critically reviewing the work of Vosniadou and Brewer, and suggested that the mental models identified by the earlier researchers may have been an artifact of the research methodology and expectations of the researchers. To counteract what they perceived as weaknesses and biases in the previous research, Schoultz et al. began their interviews with an Earth globe and related all of their questions to the globe in front of the child. They interviewed 25 Swedish children--8 first graders, 8 third graders, and 9 fifth graders--and found that nearly all of the children had no difficulty understanding that the Earth is a sphere, that people live all over the sphere, and that they do not fall off because of gravity. They found virtually no evidence of Nussbaum's notions 1, 2, or 3. Although the sample size was small, they believed that these children were representative of the population in Sweden and comparable to children in other countries as reported in the previous studies. They attributed the success of the children in their study to the presence of the Earth globe, and argued that in such studies, children should have "access to one of the cultural tools by means of which they have obviously learned to reason in such a sophisticated manner" (Schoultz et al. 2001).

Butterworth, Siegal, Newcombe, & Dorfmann (2002) challenged the results of Vosniadou and Brewer because the previous researchers relied primarily on drawings and open-ended questions. In contrast, Butterworth et al. (2002) used three-dimensional models and forced-choice questions throughout the interviews. For example, rather than asking their subjects, "What shape is the Earth?", they began their interviews with: "Is the world round or flat?" "Does it look like a circle or a ball?" Then they showed the students models of a flat disk, a hemisphere with a plastic dome, and a full sphere (like those used by Vosniadou and Brewer), and they asked the child to select the model that best illustrated the shape of the Earth. Study one included interviews of 59 Australian children and 71 English children in three age groups: ages 4-5, 6-7, and 8-9. Anticipating that children in the earlier studies may have been confused by the term "Earth," which has multiple meanings, the researchers used "world" in half of the interviews and "Earth" in the other half. They found no difference in results using the two terms. They did, however, find that the Australian children performed better than the English children, and that children in both samples did better than in the Vosniadou and Brewer studies. (By age 8-9, the children's responses to the questions were "consistently spherical" or "mainly spherical.") In study two, 45 Australian 5-year-olds were interviewed to determine the effects of the questionnaire. Half were questioned using the Vosniadou and Brewer protocol, and half were questioned using the forced-choice approach developed for study one. The investigators found that the forced-choice questions using models resulted in significantly higher performance. Butterworth et al. (2002) argued that the open-ended interview questions may have been confusing, and that "children's actual preferences for the Earth shaped as a ball emerge only through specific questioning involving two meaningful choices."

In the third study in this series, Nobes et al. (2003) used the interview method employing forced-choice interviews and the identification of premade models to study the responses of two different cultural groups living in England, divided into ages 4-5, 6-7, and 8. They found no substantial difference between the responses of 85 White British participants and 82 Gujarati British participants, and they found that the majority of students of all ages correctly identified the shape of the Earth. This group of researchers also studied the pattern of responses that children gave to various questions, and found that these patterns did not indicate that the children were applying their personal theories consistently and systematically. For example, if a child claimed that the Earth is flat but did not claim that one could fall off the Earth, the response was recognized as inconsistent. By this method of analysis, the researchers identified only 36% of the participants' responses as consistent with Vosniadou and Brewer's mental models. Nobes et al. (2003) concluded that the "picture of knowledge acquisition that emerges from these findings is of a process of gradual accumulation, piece by piece, of loosely related fragments of cultural information" (p. 72).

In summary, the three studies cited in this section present new theoretical frameworks and research methodologies for studying children's understanding of the Earth's shape and gravity. Schoultz et al. (2001) presented an Earth globe as a starting point, finding that as early as first grade, children have no difficulty describing the spherical Earth model, with people living all over the Earth. Researchers in the latter two studies used forced-choice questions, consistent with their view that open-ended questions might be confusing to children. All three studies found that children performed at a much higher level than in the studies reported in the previous two sections.

We urge readers to interpret these results with caution. Nussbaum and subsequent researchers also found that children seemed at first to understand the scientific model, but probing questions revealed that children viewed the world quite differently. Researchers of the three most recent studies chose not to probe too deeply. For example, Nobes et al. (2003) found that although 86% of their subjects claimed that the Earth is shaped like a ball, nearly half also said that a person could fall off the edge of the Earth. If the researchers had asked the children to explain how both responses could be true, a method employed in an extension of this study (Martin, Clifford, Moore, & Nobes 2001), it is possible that they would have found the notions or mental models observed by previous researchers.

4.4 Action Research in the Classroom

The research just reviewed consists largely of status studies that seek to characterize student knowledge without attention to prior instruction or the effectiveness of new instruction. In contrast, we recognize action research as studies conducted to increase the effectiveness of instructional treatments usually characterized by an iterative process in which the researchers learn from previous research, adjust their approach, and then test the improvements. Although status studies offer a valuable contribution to the research literature, action research is most useful for informing the creation of effective instructional materials.

The early work of Nussbaum & Novak (1976) and Nussbaum & Sharoni-Dagan (1983) are examples of action research. Upon discovering the ineffectiveness of instruction in the first study, the researchers improved the instructional treatment and tested the new material's effectiveness on student learning. However, even after these efforts to improve the curriculum, only 15% of the students reached the highest level of understanding of the Earth's shape and gravity concepts. More recently, Sneider & Ohadi (1998) conducted an action research study involving 539 students in grades four through eight from 18 classrooms in 10 states, aimed at helping children unravel their misconceptions about the Earth's shape and gravity and to acquire the scientific concept of a spherical Earth.

The instructional program used in the Sneider and Ohadi study was a unit in the LHS GEMS (Lawrence Hall of Science: Great Explorations in Math and Science) series entitled *Earth, Moon, and Stars* (Sneider, 1986), based on a constructivist-historical teaching strategy. In this approach, students learn not only the justification of modern scientific theories but also how and why the older theories were rejected, and how the nature of scientific inquiry changed within the discipline when the scientific community shifted from the old paradigm to the new (Duschl, Hamilton, & Grandy 1992). This instructional approach, and the instruments used to evaluate student learning, evolved over a period of more than a decade. In its final published form, the unit consists of six activities.

Activity 1. Ancient Models of the World. In the first unit, the students are asked to imagine that they lived thousands of years ago, when people in many different cultures believed that the Earth was flat, and to draw a picture showing the way ancient people might have explained how the Sun returned to the eastern part of the sky every morning after setting in the west the previous night. The students generally solved the problem by imagining that the Sun is carried back to the eastern horizon by magical animals or through a tunnel under the Earth. After the students show their drawings to the class, the teacher points out how these ideas are similar to those invented by many different cultures in ancient times. The purpose of this activity is for the students to begin thinking of a model of the Earth as a coherent system to explain natural phenomena.

Activity 2. Introduction of the Spherical Earth Model. The spherical Earth model is introduced by the teacher who explains that Greece was the center of trade routes, where people from different places met and exchanged stories about the Earth and sky. Some ancient Greeks listened to these stories and wondered how they could all be true. These people tried to invent models that provided the best explanations for what they saw in the sky. The ball-shaped Earth was one of these ideas and was probably suggested at least 2,500 years ago (long before the days of Columbus).

The teacher then hands out a questionnaire that asks the students for their ideas about the Earth's shape and gravity (see Figure 2). After the students complete their answers to the questionnaire individually, the teacher collects the papers (which become the pretest), and the students work in small groups of three to five students to decide on the best answers to the questions they just completed. Each group is given a transparent Earth globe to aid their discussions. This part of the lesson is characterized by much-heated discussion as the students try to convince each other that their answer is best--in the tradition established by the ancient Greek philosophers.

Finally, the teacher facilitates a whole-class discussion about each of the questions. Students draw their various ideas on the chalkboard and the teacher facilitates the discussion, taking care not to label answers as right or wrong. The students act as a community of scientists as the teacher helps them to identify their points of agreement and disagreement and to consider the logical consequences of alternative theories. This discussion takes one or two class periods, occasionally longer. Experience has shown that many students continue to talk about these questions with each other and their parents outside of school. (If the teacher labels some of the students' ideas "right" or "wrong" too early, the lively conversation is not likely to take place.)

A day or two after the class discussion, the teacher explains how Aristotle and Newton would have filled out the questionnaire if they were alive today. The two would have agreed on all but the last question, which asks what would happen to a rock dropped into a hole drilled all the way through the Earth, from pole to pole. Aristotle would show the rock falling to the center and stopping, because that is the resting place of all solid matter--the "center of the universe." Newton, on the other hand, would show the rock passing the center, and falling back and forth forever, or until air resistance slows it down and it settles in the center, where all forces on the rock are equal. The teacher points out that today, nearly all scientists would agree with Newton. Students are encouraged to think further about these different points of view and decide for themselves which answers make the most sense.

Activity 3. Observing the Moon. Students observe and record the Moon's changing phases and its distance from the Sun over a period of at least two weeks. They note that as the Moon moves further from the Sun, more of it is illuminated, and the side that is illuminated always faces the Sun. As a result of this activity, students become familiar with the pattern of lunar phases.

Activity 4. Modeling Moon Phases and Eclipses. A single light representing the Sun is placed in the middle of a darkened room, and the students stand in a large circle around it, each holding a ball on a stick. With arms outstretched, the students slowly move the ball around their heads, observing that the ball, like the Moon, goes through phases. More of the ball is illuminated as the angular distance between it and the "Sun" increases, and the lighted part always faces the "Sun." The students use the same model to understand eclipses and to distinguish them from phases. By using the physical model of the Moon and Sun to explain phenomena that they have observed in the sky, the students develop a mental model of the Moon as a spherical body in space. Recognizing that the Moon is a large ball in space will help some students understand that the Earth is also a ball in space.

Activity 5. Making a Star Clock. The concept behind the cardboard Star Clock is that it works because stars appear to turn in a large circle around the North Star every 24 hours. The students model this spinning motion by slowly turning in a circle as they point to a spot in the ceiling that represents the North

Star, and observe that all of the other parts of the room appear to be circling the point right overhead. The purpose of this activity is to recognize that the apparent movement of the stars can be explained if we envision ourselves living on a spherical Earth that spins on its axis once every 24 hours.

Activity 6. Using Star Maps. In the last activity of the unit, the students use star maps to recognize constellations in the night sky and to observe how the constellations rise and set over a period of a couple of hours. As in the previous activity, students interpret this activity by applying their mental model of a spinning spherical Earth.

Sneider & Ohadi (1998) conducted two studies using this instructional treatment. The first, which involved most of the subjects, was an experimental-group-only design in which teachers administered the same test to all students before and after the treatment. This study was undertaken to measure the impact of the experimental treatment. The second study included control groups to gauge the effects of maturation and of the test itself as alternative explanations for any improvements observed in the larger primary study.

The questionnaire "What Are Your Ideas About the Earth?" shown in Figure 2 was used as the pretest instrument in both studies. The same questionnaire was given two to three weeks after completion of the unit as a posttest. Development of the questionnaire was based on results of interviews described in a previous study (Sneider & Pulos 1983), and it was found to yield results very similar to interviews initially developed by Nussbaum (1979) and others.

The teachers who presented the instructional treatment and who administered and scored the questionnaire had attended a three-week summer institute sponsored by the National Science Foundation. At the institute, teachers were trained in presenting the unit and in scoring the assessment instrument. Interrater reliability (agreement between two trained educators) was found to be 97% for the Earth's shape scale and 87% for the gravity scale. In all cases, disagreements were only one level apart, and when distinguishing the highest level from other responses, agreement was 100%.

Results were that children at all grade levels in the study (four to eight) increased their understanding of the Earth's shape and gravity to an extent that was both statistically significant and educationally meaningful. A surprising finding was that the greatest gains were by the youngest children, fourth and fifth graders. Whereas the pretest data followed the expected pattern of better performance among older students, the posttest data showed that after instruction, fourth and fifth graders were as knowledgeable as seventh and eighth graders concerning the Earth's shape and gravity. However, even though the fourth and fifth graders made substantial gains, they did not all achieve 100% mastery. Seventy-two percent of these children achieved the highest level of the Earth's shape scale, and 67% achieved the highest level on the gravity scale.

The results of the second study, conducted at two sites, showed that the experimental group increased their understanding of the Earth's shape and gravity, while the control group did not. Consequently, maturation and the test itself could be ruled out as alternative explanations for the substantial gains observed in the main study.

Although the study reported here was undertaken to determine if summer institutes sponsored by the National Science Foundation had an impact on students, the results are more widely applicable in the context of other studies on children's ideas about the Earth's shape and gravity. Like the early Nussbaum studies, it was an action-research study taking place in classrooms across the United States. Rather than relying on individual interviews, which are difficult for teachers to administer given limited time, the assessment instruments were written questionnaires, which students can fill out relatively quickly and teachers can score quickly and reliably. This allows teachers to conduct research studies with their own students so that they can learn about their students' actual misconceptions as instruction begins and assess their levels of success after instruction ends.

5. ANALYSIS AND CONCLUSIONS

Returning to the questions raised in the introduction to this article, we can now draw the following conclusions.

5.1 What Are the Important Components of the Spherical Earth Concept?

As presented in the earliest papers on this topic, the spherical Earth concept is a system of several interrelated ideas: The Earth we live on is a ball in space. Our ball-shaped Earth is surrounded by a shell of air, and beyond that is empty space in all directions. The Earth does not need to be supported because there is no absolute "down" direction in space. People live all around the Earth, and are held there by a force called "gravity." Gravity pulls everything toward the center of the Earth, including everything on its surface and objects that fall into tunnels below Earth's surface. An obvious extension is Newton's theory of gravity, which predicts that an object dropped into a tunnel bored through the Earth will pass the center and fall back and forth. However, for the elementary and middle school levels, it is sufficient to teach the concept at the Aristotelian level--that "down" is toward the center of the Earth. Although several of the research articles cited in this paper focus on Earth's shape and ignore related ideas about gravity, an elementary science curriculum is incomplete if students do not understand that the idea of a ball-shaped Earth makes no sense without a rudimentary understanding of gravity as a force that acts to pull things toward the center of the planet.

5.2 How Will We Know if Children Understand It?

A wide variety of ideas for assessment have been discussed in the literature review. Most use clinical interviews as the method of choice. Although interviews are preferable in a research situation, where it is important for the researcher to be certain that every child fully understands the question and can ask follow-up questions to be certain of clear communication, it is not feasible for schoolteachers who are responsible for 30 or more students at a time. The questionnaire developed by Sneider et al. (1986) and used in the Sneider & Ohadi (1998) study provides a viable large-group alternative. The instrument could be adapted for use in a textbook, with the scoring rubric in a teachers' guide.

5.3 Is Children's Knowledge Organized in the Form of Personal Theories, or Is Their Knowledge Fragmentary?

There is no clear-cut answer to this question. Vosniadou and Brewer claim to have found definitive evidence that 80% to 85% of children apply their personal models of the Earth consistently and systematically to answer questions posed by researchers. On the other hand, studies by Schoultz, Nobes, Butterworth, and their collaborators claim evidence to the contrary. From the viewpoint of science teaching, however, the relevant question is not whether children tend to apply their mental models to new situations spontaneously, but how to teach them to do so. In this case, our task is to help children form a scientific model of the Earth and gravity and then to apply that model systematically to relevant phenomena, such as night and day, the launching of a space satellite, or the exploration of other planets in the Solar System. The series of lessons presented by Sneider & Ohadi (1998) provides one method for doing so.

5.4 Is It Important for Students To Express Their Current Understanding of the Concept as a Step Toward Learning?

This is a critical question. Schoultz, Nobes, Butterworth, and their colleagues claim that it is not necessary for students to unravel their misconceptions (presuppositions). Nobes et al. (2003) and Butterworth et al. (2002) argue that student thinking is fragmentary, while Schoultz et al. (2001) point out that student knowledge is context specific. According to these researchers, all that is necessary is to present students with appropriate information about the Earth, along with conceptual tools (such as globes) to help them understand the spherical Earth concept. Then, construct assessment instruments with minimal forced-choice answers and allow the children to use the globes that were used during instruction, and nearly all children will give the right answers.

All of the other researchers in this field, from Nussbaum & Novak (1976) to Sneider & Ohadi (1998), have presented evidence that children must unravel certain entrenched presuppositions before they can adopt a scientific model. Specifically, they must realize that the Earth appears to be flat because we only see a small part of it, and that if we could see it all, as astronauts do, we would see it as a huge sphere. They also need to realize that "down" on Earth is oriented toward the center of the Earth, and that there is no absolute "down" in space. Sneider and Ohadi proposed a method for helping children unravel these misconceptions by encouraging them to compare their personal beliefs with those of other students and to discuss the implications of different points of view. According to these researchers, if children do not learn to unravel their misconceptions, these erroneous ideas will interfere as children try to apply their conceptions of the Earth to all sorts of phenomena related to space and astronomy.

5.5 At What Age Level Is it Appropriate To Introduce the Spherical Earth Concept in its Fullest Form?

A useful construct in thinking about the optimal age for concept introduction was proposed by Vygotsky (1934) as follows: "For each subject of instruction there is a period when its influence is most fruitful because the child is most receptive to it. It has been called the sensitive period by Montessori and other educators" (104). In Vygotsky’s view, learning is essential to cognitive development, and the best time for any given learning to occur is when a child is most receptive to a topic’s instruction. This is the period during which a child has the developmental capacity to learn something new in a subject area provided that he or she has assistance from a teacher or another student. The sensitive period for a given concept is not the same for every child, so the relevant question is when most children are ready for a significant lesson on the spherical Earth concept that will help their cognitive development.

The most useful studies to determine the sensitive period for introducing the Earth’s shape and gravity concepts are the action research studies in which students’ responses to instruction are measured. The pair of studies by Nussbaum & Novak (1976) and Nussbaum & Sharoni-Dagan (1983) found that although a carefully designed audio-tutorial lesson could advance second graders' understanding of the Earth's shape and gravity to a modest extent, very few students were able to master the concepts. Sneider & Ohadi (1998) implemented an intensive series of activities with students in grades four through eight, and found that the greatest improvement was by the fourth- and fifth-grade students. (This is a little earlier than recommended by the National Science Education Standards, p. 159.) Although students in grades six, seven, and eight improved in their understanding, their gains were not as great as those of the younger students. Although the experiment did not extend to third grade, that not all of the fourth and fifth graders achieved mastery suggests that third grade is probably too early. In summary, the action research studies indicate that in grades four and five, most children can unravel any misconceptions they may have acquired, understand the spherical Earth concept in all its richness, and apply their understanding to the work of astronauts and space probes.

5.6 Recommendations

Our advice to the team of writers and scientists charged with revising the Scott Foresman Science series is as follows. Eliminate from the text for grades one through three explanations of astronomical phenomena that require students to understand the Earth's spherical shape and gravity concepts. Replace these sections with activities in which students observe, record, and find patterns in the world around them. For grades four and five, include a substantial set of activities in which students fully explore the model of the spherical Earth and the related concept of gravity. In this unit, students should be encouraged to consider their current understanding and unravel any preconceptions that they may hold, and apply the model to phenomena such as the day-night cycle. After such a unit, students may go on to explore the other planets of the Solar System through the eyes of astronauts and robotic space probes.

The reason for removing information about the spherical Earth and gravity concepts from the first three years of elementary science is aptly stated by Mali & Howe (1979) as follows: "The danger is that the child will be told and will accept the new notions of Earth, Gravity, and Space without understanding the meaning of the evidence or thinking about the implications of the new ideas" (p. 685). The time for introducing these concepts is in grades four or five, when students "can begin to construct a model that explains the visual and physical relationships among Earth, sun, moon, and the solar system" (National Research Council 1996, p. 159)

The assumption that underpins this advice is that the goal of astronomy education should be to help children acquire an increasingly sophisticated model of their place in the universe, out of what may initially be fragmented bits of information and initial ideas. The research cited in this paper indicates that constructing such a model is not easy. In some cases, it means abandoning earlier ideas that once seemed perfectly obvious and reasonable, and accepting new ideas that may be counterintuitive. Achieving conceptual change at such a deep level requires clarification of current ideas (even if those ideas may be wrong), listening to the ideas of others, thinking through the logical implications of different models, and then applying conceptual models to explain previously observed phenomena.

Although the above recommendations are grounded in the research literature, our final advice to the developers of new instructional materials about the Earth's shape and gravity is to treat all previous research results with caution and to build research into the development process itself. Only by conducting pilot studies of children's understanding about the concepts that the materials are intended to teach will it be possible to determine if the materials are in fact effective, and to decide how they should be improved. Carrying this approach to its logical conclusion, the assessment instruments should then be shared with teachers, who can use them to monitor and improve their teaching. The goal of this work is not simply for students to give the right answers on multiple-choice tests but also to develop an accurate and profoundly useful model of the Earth in space as a firm platform for exploring other planets, stars, galaxies, and ultimately, the entire universe.

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