The Development of Student Conceptions of the Earth-Sun Relationship in an Inquiry-Based Curriculum

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ABSTRACT

The study of conceptual change has long been of interest to cognitive science researchers and has tangible applications in education and curriculum design. Many theorists agree that learners must be confronted with their misconceptions before conceptual change can occur. This case study is an in-depth investigation of three fifth-grade students throughout their participation in a curriculum on Earth surface temperature. Data were collected via individual interviews and classroom observations and interactions, and were analyzed by comparing the students' thinking at various points before, during and after the unit. Throughout the study, the students exhibited misconceptions identified in current literature as well as novel misconceptions. The study also demonstrates that, although the curriculum was found to be partially effective, the students retained some misconceptions with which they began the study. In these cases, it seems that conceptual understanding is more fragmentary than theory-like, and that the depth of one's prior knowledge affects how readily new knowledge is constructed. The paper includes a discussion of student conceptions and potential implications for the design of the curriculum unit.

INTRODUCTION

As children interact with the world around them, they begin to form ideas about how the world works. Despite the fact that many of the ideas are not scientifically accurate, children find these ideas entirely plausible and adopt them as the truth. Students rarely question these experience-based explanations, even when the explanations do not align with commonly accepted scientific views, because their understanding explains a situation adequately for their own purposes. Additionally, the child's understanding is the easiest means of relating complex scientific phenomena. These factors thus help the child create a sufficient and cognitively economical explanation, and negate the need for a more complex model of natural phenomena.

In order to help students learn about Earth science, we must first examine the particular ideas with which they enter the classroom, enabling curriculum designers to develop materials that respond to these misconceptions. We must consider factors that might contribute to the persistence of such misconceptions, with the goal of recognizing and modifying any practices that allow them to remain or reinforce them. Finally, we must acknowledge that conceptual change is often a time- and labor-intensive process.

This study has two main purposes: to obtain a clearer picture of the misconceptions that students bring to the study of causes of variation in Earth's surface temperature; and to track the progression of students' understanding throughout their studies. This paper provides an in-depth exploration of three fifth-grade students as they progress through an Earth science unit on the factors that affect surface temperature. The students demonstrated several misconceptions upon beginning the curriculum that appear to have persevered throughout the course of study, although they did attain varying levels of conceptual change. An attempt was made not only to identify students' initial misconceptions, but also to investigate what their conceptual change looks like. The intent is not to quantify this change but to provide a rich description of its character. We tracked student understanding before, during, and after their class's involvement in Planetary Forecaster, an Earth systems science unit.

In the remainder of this paper, we briefly discuss misconceptions that have been identified in prior research and describe the curriculum before introducing and analyzing the students' initial ideas and their ensuing conceptual change.

STUDENT UNDERSTANDING OF THE EARTH

Throughout the past several decades, interest in studying children's misconceptions has accelerated, as researchers have begun to recognize that students do not enter classrooms with a tabula rasa, but rather enter with a wealth of informal ideas about the world and how things function (e.g., Driver, 1989; Shymansky and Kyle, 1988; Hashweh, 1986; Osborne, Bell, and Gilbert, 1983; Nussbaum, 1979). Although there has been much debate over both the terminology and the mental composition of such ideas, the central issue is that students often enter classrooms with the understandings of scientific phenomena that are not in accordance with scientifically accepted views. Regardless of the vocabulary used to refer to these ideas and of their actual composition, researchers continue to find evidence that these misconceptions are highly resistant to change, and are attempting to understand how conceptual change occurs in students (e.g., Novak, 1988; Driver, 1989; Hashweh, 1986; and Confrey, 1990) in order to design curricula that facilitate student learning.

As learning theory has developed over the past several decades, many researchers have come to agree that students must not only be exposed to correct material, but must also be forced to confront personal misconceptions in order for conceptual change, and hence learning, to occur (Hashweh, 1986). In recent years, many studies have been conducted across various scientific disciplines exploring the misconceptions that students possess. However, much of this research has focused solely on biology, chemistry, and physics, and has often ignored Earth science, thus leaving a dearth of knowledge about specific misconceptions in this domain. Mayer and Armstrong (1990) provide the vivid metaphor that "science curriculum is trapped in the century-old curricular straight-jacket of biology, chemistry, and physics [which] seems to have insured the neglect of the planet Earth systems that are our home and govern our well being" (155). Thus, it is necessary to obtain a comprehensive understanding of students' misconceptions about Earth science if educational research hopes to impact learning in this discipline.

PLANETARY FORECASTER

Planetary Forecaster is a middle school curriculum unit for Earth systems science that was developed using the Learning-for-Use design framework (Edelson, 2001). It was written by researchers in the Geographic Data in Education (GEODE) Initiative together with teachers in the Chicago Public Schools as part of a partnership called the Center for Learning Technologies in Urban Schools. Since 2000, it has been used in a variety of schools in Chicago and surrounding communities. It is currently being revised for publication as part of a comprehensive, three year, project-based middle school science curriculum. Planetary Forecaster combines computer-supported investigations of geospatial data with hands-on laboratory activities in which students observe and measure the phenomena under study. The Planetary Forecaster curriculum unit is the product of an ongoing iterative development effort that involves teachers both directly as members of design teams and indirectly as implementers who are observed or provide feedback. The curriculum has been through three revision cycles based on three cycles of classroom implementation.

Unit Scope and Sequence - The content goal for the unit is for students to understand how physical geography influences temperature at a climatic timescale. The premise of the curriculum unit is that students have been asked by a fictional space agency to identify the portions of a newly discovered planet that are habitable given information about the planet's topography, water cover, and the tilt of its axis. For simplicity, the planet has the same atmospheric make-up as Earth, is orbiting around a star with the same intensity as the sun, and has an orbit with the same radius as Earth's. This mission is designed to create a demand for understanding of the curriculum's target content.

There are four major relationships that students must understand to complete the task. The factors are curvature of the Earth's surface, tilt of the Earth's axis of rotation, differences in specific heat of land and water, and elevation. Understanding the relationships between these factors and surface temperature requires an understanding of fundamental scientific concepts that are commonly found in national, state, and local standards documents, such as the Earth-sun relationship, radiative energy transfer, conservation of energy, heat and temperature, specific heat, and the ideal gas law.

The curriculum materials place a special emphasis on forming and revising hypotheses based on evidence they have gathered. The unit is divided into seven sections that take from 1-5 class periods each. During each section, students describe the factors that they believe affect temperature, how they affect temperature (i.e., the direction of the effect), and why (i.e, the underlying causes). Students also provide evidence for these hypotheses and record any questions. They first capture their hypotheses about the factors during the initial "setting the stage" activity (described below). During the portions of the unit where they investigate individual factors, students record an initial hypothesis about how each factor affects temperature before they conduct the investigations, and they then record revised understandings following the investigation. Students use this revised description of the relationship between a particular factor and temperature when they construct their final temperature maps for Planet X. The unit is broken down as follows:

1. Setting the stage. Students articulate prior conceptions in an exercise in which they draw color maps showing their current conceptions of global temperatures. They then compare their maps with actual data from Earth and formulate initial hypotheses about the factors that influence temperature.
2. Getting the task. Students learn about their mission of identifying habitable regions on a newly discovered planet, Planet X. They are told that they will receive data about the shape, tilt, surface cover, and topography of Planet X that will help them to develop a map predicting the distribution of temperature across the planet.
3. Investigating shape. Students investigate the effect of angle of incidence of solar energy on surface temperature through hands-on labs and explorations of global incoming solar energy data for Earth.
4. Investigating tilt. Students investigate the effect of a tilted axis of rotation on temperature at different times of year, through explorations of incoming solar energy data for Earth. They observe how the bands of incoming solar energy shift with seasons.
5. Investigating surface cover. Students investigate the effect of land versus water on temperatures through hands-on labs looking at specific heat of water and soil and explorations of global surface temperature data for Earth.
6. Investigating elevation. Students investigate the effect of elevation on temperature through explorations of global surface temperature data for Earth.
7. Final Recommendations. Students identify habitable areas by looking at maximum and minimum temperature values in their temperature maps for Planet X. They present their findings and their recommendations for colonization.

STUDENTS' CONCEPTIONS ABOUT THE EARTH-SUN RELATIONSHIP

The target content for Planetary Forecaster cuts across several different areas. To support both the development of the curriculum and research on student understanding, as well as to help prepare teachers, we have attempted to identify the prior conceptions that students are likely to bring to the curriculum.

Whereas literature on students' misconceptions in Earth science is relatively sparse compared to work in other scientific disciplines, we have identified some relevant literature on children's conceptions of causes of temperature variation. Piaget (1929) found that some children think that winter's cold weather results from the

Curvature
The sun's rays hit only at the equator and spread from there
The equator is the only place on Earth that ever receives direct sunlight
The equator receives more sunlight than other places on the Earth
Tilt
Seasons result from the entire Earth being closer to the sun in summer and farther away in winter
Seasons result from the entire Earth being closer to the sun in summer and farther away in winter
Seasons result from the Earth's rotation on its axis (the Earth's Eastern and Western hemispheres, therefore, have opposite seasons
Elevation
Temperature increases with elevation because hot air rises
Temperature increases with elevation because higher elevations are closer to the sun
Mountains are cold because there are clouds on top that make them cold
Land/Water
Water is always colder than land
Water is always warmer than land
There is no difference between land and water temperatures

Table 1. Students' misconceptions about each of the four content areas addressed by Planetary Forecaster. These were identified through analysis of student work in curriculum enactments prior to the current study.

wind, and from the sun being covered by clouds. Russell, Bell, Longden, and McGuigan (1993) corroborated the cloud finding and also discovered that some students believe that as the Earth rotates, it changes its position in relation to fixed weather patterns. These students seem to think that clouds are the determining factor in weather - by blocking the sun, causing rain, or dictating a number of other weather-related phenomena.

Among the most studied areas of Earth science in the misconceptions literature is the cause of the seasons and the Earth-Sun relationship. In a study of eleven-year-olds, Dove (1998) found that many students believe that winter is colder than summer because Earth is farther from the sun in the winter. Atwood and Atwood (1996) again found that misconceptions persisted until college, providing data from student teachers, who were found to possess various alternative conceptions regarding the cause of the seasons. Thirty-nine of forty-nine pre-service teachers demonstrated alternative conceptions on the written exam, and forty-two of the same forty-nine gave answers that fit into the alternative conception category on the verbal exam. Not even half of the teachers could position the Earth-sun model to correctly depict summer in a particular hemisphere, and only one was able to correctly illustrate what happens to that hemisphere during the course of the year between summer and winter.

Philips (1991) examined more than ten years of research and compiled a list of over fifty commonly held Earth science misconceptions. His survey indicated that 4th-9th graders frequently think that the Earth's distance from the sun dictates the seasons. This same age group also hold the following misconceptions: that the sun is directly overhead (i.e., above the Earth) at noon; that the amount of daylight increases each day of summer; that the Earth's revolution around the sun causes day and night; and that the sun's revolution around the Earth causes day and night. The literature that Philips reviewed documented the fact that misconceptions often persist through adulthood, e.g., that some adults think that the sun moves around the Earth, and that this cycle occurs in less than one year's time.

In their research involving third- and sixth-graders' conceptions of the Earth-moon-sun relationships and relative movements, Jones, Lynch, and Reesink (1987) also demonstrated confusion about the Earth-Sun relationship. One particular student generated a fairly elaborate - albeit scientifically unfounded - model of the Earth-sun relationship in which day is caused by the sun's proximity to Earth, and at night the sun disappears and is replaced by the moon and moonlight. The authors additionally found that even students who know that the Earth "spins" rarely know that it spins three hundred sixty-five times a year; responses ranged from hundreds of times per year to thousands to even millions. These misconceptions about the Earth-sun and Earth-moon relationships, while not directly related to temperature, would interfere with students' understanding how temperatures vary with latitude and with seasons.

This sample of prior research describes misconceptions that could influence students' understanding of our target concepts, but we have not located research that specifically describes students' conceptions of the causes of variations in temperature with geography. Therefore, as part of the formative research we have conducted to support the development of Planetary forecaster, we have collected student work from classroom implementations and have analyzed it for students' conceptions. The misconceptions we had observed in prior classroom studies are summarized in Table 1.

A CASE STUDY OF LEARNING IN PLANETARY FORECASTER

In the 2001-2002 school year, we conducted our first study designed to track changes in students' understanding of the key concepts in the Planetary Forecaster curriculum over time. The primary goal of the study was to investigate the effectiveness of Planetary Forecaster in enabling students to develop understanding that they can recall and apply when appropriate. A secondary purpose of the study was to capture the students' misconceptions about the factors that affect surface temperature. This was a small-scale study in a single classroom designed to collect detailed information about a small number of students. The study focuses on the content covered in the first portion of the curriculum. This portion investigates the differential heating of Earth based on latitude and seasons, or the factors that are called curvature and tilt in the curriculum.

Classroom Context - The data reported here was collected in a 5th grade classroom of 27 students in a Chicago Public School with a diverse, urban population. While the curriculum was designed for 6-8th grades, the teacher, Martha (a pseudonym), had successfully implemented other middle school units in her 5th grade classes. We decided to conduct this study in her classroom despite the age of the students because of concerns about the consistency between the curriculum designers' goals and the pedagogical approaches of the teachers we had access to.

Classroom observations confirmed that Martha's approach was consistent with the goals of the designers. She, successfully created an inquiry-based learning environment in which students investigated phenomena rather than simply receiving information about it. Martha repeatedly told her students, "I'm not going to tell you all the answers; you'll have to come up with them yourselves." Martha had high expectations of her students, and the discourse was at times above a typical fifth-grade level; for example, these fifth-graders referred to times when they had to be "metacognitive," or, "think about [their] thinking." Class sessions were rarely lectures, and generally involved significant discussion among Martha and the students, with Martha often asking open-ended questions and prodding her students to elaborate on their ideas. She also employed brainstorming sessions and produced a classroom environment where all comments and questions were valued and respected. During class discussions, students would regularly use a peer feedback format that Martha had taught them prior to this study. When a student wanted to comment (or is asked to comment) on another student's thoughts, the student should first say something positive about the previous response, and then provide an alternate viewpoint or constructive criticism. Finally, Martha structured her science class so that her students paralleled scientists. When students were confused about anomalous data in a lab, she would ask them what real scientists do in this situation, to which they would respond "recollect the data," and, time permitting, would do just that. Overall, the classroom environment approached the ideal for an inquiry-based curriculum such as Planetary Forecaster.

Curriculum Context - The study focuses on the portion of the curriculum, in which students investigate the effect of Earth's spherical shape and the tilt of its axis of rotation on the intensity of the incoming solar energy at different latitudes at different times of year. Students engage in several hands-on and computer-based activities to support their construction of knowledge about this content. All the activities are designed around a conceptual model of incoming solar energy as parallel "rays" of light. We selected this model of insolation in the design of the curriculum because it is sophisticated enough to explain variation in heating at different latitudes but simple enough to be accessible to middle school students. In the portion of the unit on the effects of curvature, students engage in two knowledge construction activities. In the first activity, students conduct a hands-on lab where they use a penlight to represent the Sun and measure the area of the light beam from the penlight as it strikes paper at different angles. Each angle of the paper represents a different angle of incidence of sunlight from the equator to the poles. This lab is designed to demonstrate that with increasing angles (as you move toward the poles), the same amount of light spreads out over a larger area, resulting in a lower amount of energy per unit of area. The second activity allows students to see data visualizations of measured incoming solar energy showing the same decrease in energy intensity at a global scale that they viewed in their hands-on lab. In the section on tilt, students conduct a hands-on investigation with globes and penlights, in which they process the globe around the light source observing which portion of the globe receives the most and least direct sunlight at the equinoxes and solstices. This activity, too, is accompanied by a computer activity, in which students compare visualizations of Earth's incoming solar energy at each season.

Data Collection - Data were collected primarily via pre- and post-interviews, and were supplemented by student work, class participation, and classroom interactions between the researchers and the students. Three participants were interviewed individually before beginning the curriculum and again near the end. The purpose of the interviews was to elicit more in-depth explanations from the students, by probing their understanding of involved concepts in a way that could not be done on a paper-and-pencil test. The teacher selected students based on the interviewer's request to include students of varying academic abilities who were capable of articulating their thoughts fairly well. Martha's self-contained classroom hosted a wide spectrum of abilities and academic performance, and she selected students at different levels of that range. The selected students ranged from low-performing to high-performing, and all were able to verbalize and illustrate their thoughts for the interviewer and in the classroom.

The interviews were designed with the intention of examining not only what students think happens in temperature-related phenomena, but also why or how they think that event happens. The content of the pre-interview included all four factors covered in the curriculum. A main question for each of the four content areas was generated, and, based on prior research and expected student responses, follow-up questions contingent on the response were included in the script. Students were asked to draw pictures to aid their verbal explanations, especially for the questions involving the Earth-sun relationship and the seasons. The post-interview focused mainly on the Earth-sun relationship and effect of the curvature of the Earth on intensity of sunlight. It also touched on the seasons, a topic that the class had partially covered.

Although most data were the result of the interviews, additional methods of data collection were used to supplement the pre- and post-interviews. We also captured data on student participation in class and lab sessions to triangulate interview data. The class was observed two to three times a week throughout the duration of the implementation. During lecture and whole-class sessions (approximately half of the classes were run in this format), the researchers sat in the back of the classroom and record field notes. During small group sessions, the researchers occasionally worked with various small groups in the same manner as the teacher - facilitating discussion, attaining a grasp on student understanding, answering questions, etc. Additionally, student work completed either in class or as homework assignments was collected as data. Many of the assignments were completed in small groups of three to five students in class.

Results - In this paper, we present data for the three interviewees. At the time they were interviewed, the class had only completed the portions of the curriculum dealing with curvature and tilt; therefore the analysis is

	Why is Florida warmer than Alaska?	What causes the seasons?	Relevant misconceptions
Alice - pre	• Florida receives light from a warmer part of the sun • The sun rays that hit Florida are stronger (are longer and carry more heat) than those that hit Alaska	• Sunlight has different properties	• Sun rays can curve and hit parts of the Earth not facing the sun
Alice - post	• Florida receives more direct sunlight (closer to a 90-degree angle) than Alaska • Temperatures decrease farther from the equator	• Seasons are caused by the tilt of the Earth; incomplete explanation	• Heat and light intensity increase with the area that light covers • Sun rays curve slightly, but only by the poles, and cannot hit part of the Earth not facing the sun
Matthew - pre	• Regardless of tilt, the equator is the hottest part of the Earth because it is in the middle • Temperatures decrease farther from the equator	• Sunlight has different properties • The side of the Earth facing the sun experiences summer	• "Maybe" sun rays can curve
Matthew - post	• Florida receives more direct sunlight (closer to a 90-degree angle) than Alaska • The angle that the sun hits the Earth increases farther from the equator • The light has to cover a larger area farther from the equator (he does not relate this to his previous assertion)	• The "back" side of the Earth is not winter; it receives sunlight when the Earth rotates • The Earth is closer to the Sun in summer due to its orbit	• If the Earth were not curved (if it looked like a notebook standing vertically), the middle would still be the warmest • Sun rays cannot curve, but have to "stretch" to reach the poles • Light hits one place "directly" and then spreads out; it is indirect in the places to which it spreads, where it is less intense
Alex - pre	• The equator is the warmest part of the Earth because of its concentration of heat-trapping gases	• The side of the Earth facing the sun experiences summer	• Sun rays curve "a tiny bit", near the poles • Tilt changes as the Earth moves around the sun
Alext - post	• The equator always gets "more direct" sunlight, with no coherent explanation of direct sunlight	• Incoherent reasoning; tries to incorporate tilt, curvature, Earth's movement around the sun • The side of the Earth facing the sun experiences summer	• The Earth's curvature affects temperature by preventing the sun from hitting the "back" of the Earth • If the Earth were not curved, the side facing the sun would receive more direct sunlight than the other side (he has trouble decomposing the Earth into anything smaller than the whole side)

Table 2. Students' understanding of temperature change and sunlight hitting the Earth, before and after the relevant curriculum sections.

focused on the Earth-sun relationship and its influence on temperature. All three student can be characterized as initially having fragmented and mostly incorrect conceptions and each student achieved various levels of conceptual change. Results are summarized in Table 2.

Alice

Before the Unit - Alice revealed initial conceptions that were not documented in prior research or previous implementations of Planetary Forecaster. When asked why Florida is warmer than Alaska, she indicates that different parts of Earth are heated by different parts of the sun, and that Florida receives its sunlight from a warmer part of the sun. She draws a picture showing Florida receiving longer sun rays than Alaska (Figure 1a), and in response to the question, "Does the way sunlight hits the Earth have to do with temperature at different places?" answers that the strength of a ray of sunlight is determined both by its length and the part of the sun from which it originates (Figure 1b). In answer to both questions, she indicates that longer rays carry more heat. Alice also draws rays of sunlight that curve, including some that curve around Earth to reach portions of the globe that are facing away from the sun.

Alice's description of the seasons is very disjointed. She knows that it is winter in the southern hemisphere when it is summer in the northern hemisphere. However, she is unable to explain why, and she presents several partial arguments about the spinning of Earth on its axis, the movement of Earth around the sun, and "maybe because of the atmosphere." In answer to a question asking why it was cold on the day of the interview (a winter day) even though it was sunny, she says that the sunlight is somehow different, a misconception that was found by Roald and Mikalsen (2001).

During the Unit - Despite being talkative in her interviews, Alice spoke very little during class

Figure 1. (left) Drawing from Alice's pre-interview. This drawing shows the longer sun rays reaching Florida, and the shorter sun rays reaching Alaska. (right) Drawing from Alice's pre-interview. Alice's more general drawing of how the rays of the sun reach the Earth. The dark spot on the sun was drawn to indicate a particularly warm portion of the sun from which some rays originate.

discussions and groupwork. However, on two occasions , researchers did observe her comments or diagrams that were consistent with her pre-interview statements about the sun's rays. Verbal comments and written answers from the penlight lab revealed that she observed that the area covered by the penlight increased as the angle became more acute; however, she did not recognize that the brightness of the light decreased. Making this observation is critical to understanding that the increase in area results in a decrease of intensity. The likelihood of a student understanding the relationship between angle and intensity in the absence of this concrete observation is diminished because the student must instead apply the abstract principle of conservation of energy. Alice, in fact, does not demonstrate in her lab write-up that she understands the relationship between angle and intensity.

Following the Unit - In the post-interview, Alice explains that the equator is the warmest part of the Earth because it is almost at a 90 degree angle to incoming sunlight and therefore receives the most direct light. She does not mention differences in length of rays or refer to rays that originate in different parts of the sun. In answer to the questions about why Florida is warmer than Alaska, she says:

Researcher: Last time we talked about…Florida and Alaska…why again would it be warmer in Florida than Alaska?
Alice: I think it was because Florida would get part - part sunlight - part direct, but it's not really direct, it's like at a slanted angle, but it would be at ninety degree
R: Ok, so it would be more slanted than ninety…What kind of sunlight does Alaska get?
A: I don't think Alaska gets that much light.
R: Ok, so they just get less? Do you know why they might get less than Florida?
A: Less direct sunlight

As evidenced in this conversation, Alice has changed from her pre-interview stance that different types and length of sun rays determine why certain places on Earth are warmer than others. Her answers indicate that she has absorbed part of the concepts from the curvature section of the curriculum - that the angle or directness of light hitting the Earth affects temperature- and that less direct light causes colder temperatures, but she cannot apply the full explanation. This was expected as noted above, when she failed to grasp the relationship between angle and decreased intensity in the lab investigation of this concept.

Despite correctly equating less direct sunlight with colder temperatures, Alice reverses the relationship between angle of incident light and intensity, as illustrated when asked explicitly about this relationship. She states consistently that heat and light intensity increase with area, claiming that the same amount of light spread out over a larger area has more heat and greater intensity than it would spread out over a smaller area. This thinking is parallel to her earlier assertion that longer sun rays carry more heat; she appears to quantify heat with light.

In addition, while she has mostly eliminated curved rays from her drawings, when asked about the difference between temperatures at the equator and the poles, she explains that at the poles it is cooler because the light has to curve to get there, and she draws curving lines of light arriving at the poles.

Summary - Although Alice does establish certain correct relationships, she fails to correctly establish others. She never connects the angle at which light hits to the area covered by the light, and she establishes an inverse relationship between area and light intensity. It seems that Alice's more radical misconceptions have been completely replaced, which is promising. As expected, though, not all of the complex interrelations have yet been formed. Although certain correct conceptions have been adopted in their entirety, others have been acquired only in part. This evidence from Alice's learning certainly supports a theory of conceptual change that is more gradual and piecemeal in nature (e.g., DiSessa, 1988; Posner et al., 1982).

Additionally, it can be argued that Alice's learning was facilitated by the fact that the ideas with which she entered the curriculum were extremely disjointed, and that this lack of concrete relationships in her prior knowledge served her well, as she had fewer hindrances impeding acquisition of new information. This relative dearth of deeper prior knowledge seems to have aided her accommodation of new knowledge. Because Alice lacked a structure into which she could assimilate the new information, her prior knowledge did not serve to obstruct or misinterpret the new information.

Matthew

Before the Unit - Matthew was reluctant to elaborate or speculate when he was unsure. He stated with clear conviction that the reason Florida was warmer than Alaska was because it was closer to the equator, but he was unwilling to elaborate on why proximity to the equator affects temperature. When asked about the differences in temperature between seasons, he said that the winter sunlight is somehow different from summer sunlight, similar to Alice's response . Matthew suggests that winter sunlight does not hit Earth "as hard", but he does not offer an explanation of why. He initially states that seasons change not only between northern and southern hemispheres, but also between the eastern and western hemispheres. Upon reflection, though, he changes his mind, stating that the side facing the sun is warmer, so it would be summer there, and states that seasons change strictly from east to west. This explanation reveals a confusion between the daily rotation of Earth and its annual revolution around the sun.

During the Unit - Like Alice, Matthew was unable to put together all the pieces following the penlight lab. He appeared to understand the relationship between angle and area, but he did not make the connection to intensity. On his lab report, his vague answer stated, "The light gets less direct light and the temperature decreases."

Following the Unit - Matthew demonstrates different conceptions in his post-interview than he exhibited in the pre-interview, which we also saw occur with Alice. Although he uses some of the terminology from the curriculum, such as "direct" light and can offer correct definitions, it is clear that his understanding is incomplete and even inconsistent with the definitions he states. Like Alice, Matthew can correctly explain what direct sunlight is. However, unlike Alice he does not spontaneously use directness to explain the temperature difference between Florida and Alaska. In fact, his initial answer is almost word for word the same as his pre-interview.

Researcher: …[last time] we had been talking about how Florida is generally warmer than Alaska. Do you have ideas about why this might be?
Matthew: Because it's nearer to the equator.
R: It's nearer to the equator? What does the equator have to do with it?
M: No matter what the tilt is, the equator is - gets hit by the sun the most.
R: Ok. Does it get hit differently than other parts of the Earth?
M: I think it gets hit more direct.
R: What do you mean by direct?
M: Like at a 90-degree angle
R: What angle do other parts of the Earth get hit at then? Like a bigger angle, a smaller angle, or does it change?
M: Maybe a larger angle
R: Larger angle? Ok. How is this tied into how direct the sunlight is?
M: Um, because - well, I'm not sure.
R: Ok. Do you have ideas about it?
M: No.

As evident above, Matthew fails to relate the changing angle to indirect light. In this exchange, he mentions neither the size of the area covered by light, nor light intensity, in relation to directness of the sunlight. Later in the interview, however, the interviewer returns to the question of why temperatures become cooler as one goes away from the equator. This time, he does attribute temperature change to the light having to cover a larger area (farther from the equator), but again fails to incorporate light intensity into his explanation and fails to relate area to angle. In no place in the interview does he relate any of this to curvature or the Earth's shape.

Following this exchange in the interview, Matthew was asked to draw a picture to explain how the sun's rays hit the Earth. He affirms that the rays cannot curve, which differs from his undecided position before the unit. Matthew draws horizontal lines emanating from the sun and hitting the middle portion of the Earth, and then explains that they "would have to stretch" over the Earth's surface to hit the poles. He labels the equator, the Tropic of Capricorn, and the Tropic of Cancer as parts that are hit by the sunlight; he does not believe these are the only parts of the Earth that the light hits, but the only additional place he specifies is the area between the tropics. Matthew is unsure if sunlight ever hits the poles, and knows that the "back" side of the Earth receives sunlight when the Earth rotates, which is in contrast with his pre-interview misconception that the back of the Earth experiences winter. Finally, he equates "intensity" with how "direct" light hits, using "directness" in a different context than that he defined earlier. In this case, the place hit by the light is more direct - and thus the sunlight is more intense - than the places to which the light spreads.

At this time, Matthew's understanding of the seasons has shifted from the misconception that the side facing the sun has summer to another misconception - that, because of its orbit, the Earth is closer to the sun during summer and farther during winter, therefore making it warmer in the summer due to the Earth's proximity to the sun, a finding which has been reported consistently in previous research (e.g., Roald and Mikalsen, 2001; Dove, 1998; Schoon, 1992; Philips, 1991). Matthew discusses the Earth's tilt without relating it to the seasons, but instead discusses it in relation to his second description of direct light. Again, he uses "directly" as more similar to how he used it with intensity, in that directness is proportional to how close to a place the sun hits.

Summary - After the curriculum, Matthew, too, demonstrates several ideas that differ from when he entered the unit. Although he now uses some of the terminology from the curriculum - such as "direct" light - and can offer certain correct definitions, it is apparent that Matthew's understanding of the terms and the phenomena is incomplete. Matthew also struggled tremendously trying to decompose the one side of the

Earth facing the sun in order to think about how the sunlight hits different parts within this side, as opposed to how the sunlight hits this whole side versus the other sides. After the unit, Matthew knows that the "back" side of the Earth receives sunlight when the Earth rotates (such that this side now faces the sun), which is something he acquired from the curriculum. Regarding the seasons, Matthew's learning is interesting in that once he starts to gain some background knowledge, he goes from one misconception to another: that seasons result from the entire Earth's proximity to the sun. Whereas Alice began to acquire the tilt component of the cause of the seasons, Matthew instead assimilated the motion component, again providing evidence that learning occurs in pieces and that these pieces are interpreted according to the individual learner's prior knowledge.

Of all the concepts, though, the equator seems to be particularly problematic for Matthew. It is apparent that he has prior knowledge of the warmer temperatures there, as he mentions it several times before beginning the curriculum. This knowledge seems to obstruct how he interprets new information relevant to this, and especially hinders his learning about angle. Matthew may think there is something intrinsic about the middle that makes it warmer than other places, as evidenced by the post-interview activity in which he realizes that the angle at which light hits the flat surface does not change, yet he still thinks the middle would be warmer.

Alex

Before the Unit - Alex was the least forthcoming of the three. In the pre-interview, he declined to speculate about why Florida is warmer than Alaska. His misconception about the equator being warmer than the poles is unlike any other seen in the class or the literature, and cannot be classified as the others under "sunlight hitting the Earth." Like many students, Alex answers that the poles are colder because they are far from the equator. However, his reasoning is that "the equator has most of the gases" that hold heat in, and these gases spread out farther from the equator. When asked which gases, he names several - helium, oxygen, nitrogen, and carbon dioxide.

Of all his answers, Alex was most confident in his explanation of the seasons:

Researcher: Do you have ideas about why it's hotter in the summer and colder in the winter?

Alex: Yeah, because the Earth rotates and revolves around the sun. While one side has summer, the other has winter.

R: When you're talking about sides of the Earth, what do you mean?

A: Um, like front and back.

(Student draws a picture with a line separating the Eastern and Western hemispheres.)

This conversation illustrates that Alex enters the unit with a common misconception, that the side of the Earth not facing the sun experiences winter. He confuses the day/night difference with the seasonal difference, similar to Matthew's responses. Following this exchange, Alex continued to explain that the sun cannot hit the back of the Earth, so the "front" would be warmer. According to him, the Earth's rotation on its axis makes one side warmer, thus changing the temperatures. He very clearly explained that the Earth revolves around the sun once a year, passing through all four seasons, but that it also spins as it revolves, and that this spinning is the only cause of the seasons. When asked where it will be summer when Chicago has winter, Alex pointed to places on his drawing on the Eastern hemisphere, such as Asia. When asked if he had ever heard people say that when it is winter in North America, it will be summer in South America, Alex responded that he has not heard that, but initially agreed that it could be true. However, when asked the question of how that could happen if they are both facing the sun, he mentioned something vague about the Earth revolving around the sun; upon further probing, he adamantly stated the misconception that North and South America have the same season.

Alex's understanding of sun rays was somewhere in between those of Alice and Matthew: he thinks that they curve, but "just a tiny bit," by the poles. He stated the places near the equator are for the most part hot, and reasoned that the sun mostly hits the equator, without mentioning the gases he discussed earlier. Alex did, though, explain that sunlight does not only hit the equator, specifying that it does in fact hit everywhere along the side facing the sun.

Following the Unit - In his post-interview, Alex no longer mentions the "heat-trapping" gases he referred to in his pre-interview. He now explains the difference between Florida and Alaska in terms of their distance to the equator. He explains that the equator always "gets more sunlight", which he clarifies as "more direct," but he is unable to explain directness any further. He does not mention the angle that sunlight hits the Earth, nor does he refer to area or intensity. He does mention curvature as a factor in temperature on two occasions in the interview, but he does not connect curvature to angle, area, or intensity. Instead, he uses curvature to explain the fact that it prevents sunlight from hitting the side of the Earth away from the sun. Alex persists in his belief that seasons change between eastern and western hemispheres because different sides of the Earth face the sun in different seasons. Overall, his explanations are disjointed as illustrated by this answer to a question following up a statement he made about tilt and seasons, "The tilt makes like part of one side get a season and the curvature makes the other side get the opposite season." Alex appears to be trying to accommodate the idea of tilt that was introduced in the curriculum into his original conception that seasons change depending on which side of Earth is facing the sun.

Summary - Of the three interviewees, Alex's ideas after the curriculum are the least-developed. He uses the fewest of the terms from the curriculum, and the one that he does incorporate - curvature - is used in a context that differs from its intended significance. Alex still possesses his original misconception that seasons result from one side of the Earth facing the sun, but he also attempts to weave in other elements to his explanation. This results in a rather incoherent explanation, but in accordance with the perspective that learners attempt to assimilate new information into their prior knowledge (Piaget, 1929; Posner et al., 1982).

Alex was remarkably challenged in attempting to conceptualize one side of the Earth as being composed of different parts. This difficulty may have resulted from the strength of his misconception entering the curriculum that the side of the Earth facing the sun has summer; he certainly gave this factor much credit in affecting surface temperature, and was the one idea which he discussed often.

Another initial misconception, however, has been abandoned: Alex's radical idea of the existence of highly concentrated, heat-trapping gases around the equator. This lends evidence to the notion that ideas that are more similar to the new information are more likely to be used to interpret it; because the gases were not mentioned throughout the curriculum and did not seem relevant at all, it was easier for Alex to release this idea than to release others.

Finally, Alex interprets the significance of curvature very differently from its actual role in determining temperature. Instead of relating curvature to changing angles or light intensity, he sees it as blocking light from hitting the back side of the Earth. This is understandable given his persistent misconception about the cause of seasons and his skewed perspective of the significance of different "sides" of the Earth. This emphasis has been incredibly debilitating in Alex's learning process and serves as a strong example of how one's prior knowledge is used to interpret - and, in this case, inhibit - how new information is perceived.

DISCUSSION

While its scope is limited, this study has yielded valuable results. The results have some implications for our questions regarding the effectiveness of this curriculum. Additionally, the study has documented important misconceptions that can influence outcomes for students in Earth science education.

Implications for the Design of Planetary Forecaster - There is reason for optimism in the fact that significant misconceptions that appeared in all three pre-interviews were no longer apparent in the post-interviews (although additional assessments would be necessary to verify that they did not reappear at a greater interval following the curriculum). All three students understood the central relationship of this portion of the curriculum, that temperatures decrease with increasing latitudes. To varying degrees, they understood that this is a result of differences in sunlight. Alice articulated this relationship most clearly, although Alex, who articulated it least directly, correctly answered questions asking about it on the post-test. However, none of the students was able to bring together all the pieces that the section was trying to teach in order to connect angle of incidence to intensity of sunlight (via conservation of energy) and to use this relationship to explain differences in temperature. Similar to Vosniadou and Brewer's findings (1992), it appears that while the students were able to incorporate some pieces of new information into their pre-existing mental models, they preserve as much information from their previous models as possible. Overall, based on the progress of these three students, one can conclude that the curriculum is making a difference, but it would not be possible to conclude that it is being successful.

We have several hypotheses for why the students are not achieving a better level of understanding of the target concepts. The first is that fifth grade students may not be developmentally ready for the abstract reasoning that this unit requires. There is evidence for this in the fact that they are able to understand directly observed relationships, such as the relationship between angle and area, but are not able to extend this via an abstract principle such as conservation of energy, to understand the relationship between angle and intensity This is probably an important factor in explaining what we have observed.

Another hypothesis explaining why students did not achieve the desired depth of understanding is that the curriculum does not directly address important prerequisite understanding. To understand the implications of angle of incidence and tilt for temperature, students must understand the "ray" model of light and must understand the Earth-sun relationship, including the shape of Earth's orbit, period of Earth's revolution around sun, and period of Earth's rotation around axis, well enough to overcome common misconceptions. The curriculum assumes that students understand these concepts or that they will pick them up as a result of their experiences with the curriculum. In fact, there is some evidence that students do "pick them up." For example, Alice mostly abandoned her theory of curving rays of sunlight, despite the fact that there is no activity that directly addresses the nature of these rays, although there are numerous exercises that use straight arrows to represent sunlight. Presumably, the curriculum could be more effective if it were to target these important pre-requisite concepts and if it were to include activities that directly address problematic misconceptions, such as those documented here. As the students have achieved a partial but incomplete level of conceptual change and understanding, it may also help to implement the curriculum for the same students in subsequent years, in order to reinforce the concepts.

Our final hypothesis raises questions about how well Planetary Forecaster actually creates demand for its learning objectives. The students' task does not demand that they understand the reasons that latitude and seasons effect temperature. It simply demands that they know what the relationships are. In the end, the task requires that students apply their understanding that temperature varies with latitude and how. It does not explicitly require that they are able to explain why. In fact, all three students demonstrated in their classwork, class participation and in their post-interviews that they do know that temperature decreases as you move away from the equator. It is possible that a re-design of the curriculum that placed a greater demand on explaining why the four factors affect temperature would be more effective. On the other hand, it is also possible that students are not sensitive enough to the actual demands of the task that their learning of the that and the how but not the why is the result of the knowledge demanded by the task.

Novel Conceptions - While our survey of the misconceptions literature has not yet been exhaustive, this study has exposed some student conceptions that we have not found in either the literature or our previous implementations. We also observed interesting differences in the persistence of misconceptions among our subjects. Alice, who mentioned no prior conceptions about the relationship between Earth's shape and the intensity of incoming solar energy, seemed to have made the most progress toward understanding the effect of angle of incidence on intensity. On the other hand, both of the other subjects, who had prior conceptions about the influence of the Earth's spherical shape-that it caused the seasons by hiding Earth's opposite hemisphere from the sun-did not appear to have been able to accommodate any understanding of the role of angle of incidence into their understanding. It would appear that they experienced direct interference of their prior conceptions with the new content, where Alice did not.

Three new misconceptions appeared in the data reported above. The first is that the rays of the sunlight from the sun can curve around and reach portions of Earth that are not facing the Sun. Both Alice and Matthew displayed versions of this conception. Alice, furthermore, believed that different portions of the sun sent rays of different strength to Earth and indicated that the farther that rays of light traveled, the stronger they are. In the field notes from Alice's interview, the interviewer noted that the areas of extra warmth that Alice drew on the sun resembled pictures of sunspots from the popular press. It appears likely that whatever she had previously heard about sunspots had contributed to this conception. There have been occasional reports in the popular media about the effect of both sunspots and solar flares on Earth's climate. Alex also displayed a prior conception that was likely influenced by popular press accounts. He speculated that temperatures are higher close to the equator because of heat-trapping gases. A build-up of heat-trapping gases (so-called "greenhouse gases") are considered to be responsible for global warming by the mainstream scientific community, and it's likely that Alex has seen some descriptions of global warming either in school or through mass media.

The value of identifying these misconceptions is that we, and other designers working in this area, can create materials that prepare teachers for how to address such misconceptions. The evidence from the three students in this study is that the activities are helping students to construct new understanding that more closely resembles scientific understanding, but it does not fully address these students' preconceptions.

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