

Preconceptions about earth science among students in an introductory course

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Introduction

Although the Third International Mathematics and Science Study found that most eighth grade students like science and feel that they are doing well in it [Geary, 1997], fewer than one-quarter of U.S. adults can define DNA and only one in eleven knows what a molecule is [Augustine, 1998]. Hence the motivated, bright young people described by the study somehow become scientific illiterates despite the best efforts of elementary, secondary, and college level instructors.

This phenomenon has prompted various investigations into reasons why students have difficulty learning science. One possibility is illustrated by the famed video [Shapiro *et al.*, 1988] showing that most of the graduating Harvard seniors surveyed confidently attributed the cause of the seasons to changes in the distance between the earth and sun, rather than the earth's tilt. They had a clear conception of the answer - but it was wrong.

Larger, more formal studies have shown that students often enter introductory science courses with erroneous preconceptions which can keep them from understanding the material. For example, a study at Arizona State University [Halloun and Hestenes, 1985a,b] tried to determine whether an introductory physics course changed the way students thought about the physical universe. Most students entered the course with a "common sense" view of physics, essentially "a cross between Aristotelian and 14th century ideas." After the course, with its typical attention to Newton's laws of motion, re-testing showed that the course made little difference in the way students thought. Even many "A" students continued to think like Aristotle rather than Newton. They had memorized formulae and learned to "plug" numbers into them, but did not change their thinking. Instead, they interpreted what they heard about motion in terms of "common sense" theories they had developed over the years. These results were surprisingly consistent regardless of instructor or teaching style.

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The "literacy test"

To see if the same difficulty may apply in teaching introductory earth science, we have begun to explore the question of what preconceptions about earth science students are likely to bring to an introductory course, with the long-term goal of seeing how teaching affects these preconceptions. We gave an open-answer format "literacy test" to 149 students taking a standard ("rocks for jocks") introductory course at the University of Illinois at Chicago which satisfies a distribution requirement. Four students were majoring in a physical science, 33 were majoring in social sciences, and the others were majoring in the humanities and education. For most, their last exposure to chemistry, physics, or mathematics was in high school; few had any mathematics beyond introductory calculus. 60% had taken earth science in high school, 5% had a college geology class, and 35% had no previous earth science beyond elementary school.

The test covered topics in introductory earth science as well as concepts from other sciences relevant to these topics. Although not every student answered every question, each question had enough responses to give a sense of how the students think. Answers were sorted into broad categories and examined for general trends.* Our goal was not simply to decide whether answers were "right" or "wrong", but to learn how incoming students think about various topics. Hence, answers which are either factually incorrect or not what an instructor might have sought illustrate concepts that need attention in class.

Students' views often combined ideas which instructors view as contradictory. For example, although most (60%) sketched Earth orbiting the Sun and the Moon orbiting Earth, 18% had both the Sun and Moon orbiting Earth, and 13% had both the Moon and Earth orbiting the Sun (Figure 1). Similarly, 12% of the sketches of earth structure showed flat layers within a spherical earth.

Often, many of the answers to a question designed to elicit the ultimate cause of a phenomenon demonstrated a technically correct but irrelevant answer**. For example, 21% of the answers to "How does a compass work?" were "It tells you the direction that you are going," whereas 57% cited magnetism and 12% cited gravity. Such answers illustrate that the way instructors and students think about material can be quite different.

Logical contradictions were common. For example, about 25% of the students gave answers in which the dinosaurs died before life began or had the Earth younger than life. Some misconceptions result from confusing separate phenomena which are often mentioned together: most students believe that global warming is due to the destruction of the ozone layer and only a few cited an increase in CO₂ levels. Others reflect an invalid hypothesis: many students believed that there exists a magma layer within the Earth, and most believe that chemical reactions are the source of the Sun's energy.

Some answers demonstrated a "common sense" view of earth science to that of the students in the Arizona State study; Dykstra [1997] refers to these as "preconceived notions". For example, 33% of students attribute the Mid-Atlantic Ridge to a rise in water levels, and 26% believe that it is due to a collision of two plates. Students also lack a common referent

*The test, population and results are summarized on a WWW page
<http://www.earth.nwu.edu/people/seth/Test>

**Recall the joke in which a lost pilot realizes he is near Redmond, WA when the response to "where am I?" is "you're in a helicopter."

for geological time. As many students put the extinction of the dinosaurs before 1 Ma as placed it from 10 to 90 Ma. Many students placed the beginning of life at a few Ga, but a significant number placed it at less than 1 Ma. Smaller time periods can also cause confusion; even though most students correctly gave the length of a year, nearly half believed that the Moon orbits Earth once each day.

Quite frequently effects were attributed to unrelated causes; for example, earthquakes and volcanism were frequently attributed to warmer climates and the ocean because they happen in Hawaii and California. Similarly, 27% of the respondents attribute the refraction of light in water to the motion of the water, and 15% believe that temperature is the equivalent of climate.

Implications

Our initial conclusion is not surprising: many students in introductory earth science classes have difficulty with numerical concepts (millions versus billions of years) and are confused both about basic science (only 55% expect that a bowling ball and a billiard ball dropped from a tall building will hit the ground at about the same time) and about specific results relevant to earth science (only 17% attribute seasons to the tilt of Earth's axis). Although tests at various colleges and universities would be needed, we suspect such confusion is fairly typical (Harvard and UIC students do about as well on the seasons question). Hence it seems that most students not planning to major in science have absorbed little from their elementary and high school courses.

This effect may be part of the reason introductory earth science is a challenging course to teach, even relative to introductory courses in other sciences. Many students are in a earth science class precisely because they have little interest in science, are uncomfortable with it, have avoided it as much as possible, and seek the easiest way to satisfy a distribution requirement. They have learned little about science to date, and see little reason to learn more now. In contrast, many of the students in introductory physics, chemistry, calculus, or biology have some interest or need to learn the material. (Geology, for example, is the only science not required for medical school). Hence any difficulty encountered in teaching introductory physics may be compounded for earth science.

Given this challenge, there is considerable interest at present among earth scientists in exploring methods to convey better both the content and excitement of our science to students [e.g. *Geoscience Education: A Recommended Strategy*]. These efforts are similar in spirit to efforts to upgrade elementary and secondary school science education, such as the AAAS Project 2061 [AAAS, 1989].

Although much of the focus is on providing information better, it may well be that there are key areas where more effort than traditionally placed needs to be spent changing misconceptions. This possibility is suggested by theories in the educational community about how new concepts are learned, as summarized in the AAAS [1989] report *Science for All Americans*. Rooted in the ideas of Jean Piaget [Inhelder and Piaget, 1958; Piaget, 1963], the theories have continued to mature and evolve in the research of the learning sciences and in the theories of sociocultural constructionists [Schwartz and Reisberg, 1991; Wertsch, 1991]. The key aspect of these theories for our purposes is that humans construct rather than receive their notions about reality and that existing notions - actually often complex networks of associations in memory - influence how they construct new ideas. In one formulation, illustrated in Figure 2, people are assumed to pass through three stages when incorporating

new concepts into a mental model: assimilation, disequilibrium, and accommodation. People try to assimilate sensory input, including words they hear or read in an explanation or observations in an experiment, in terms of existing models of reality, comparing and contrasting the experience with notions they already hold. When they notice and remember something, they connect it with something already existing in memory that is itself, associated with other remembered items in a network of associations, and in that way try to make sense of it. If they have, for example, a model about how a process such as objects falling due to gravity works, they try to associate all data about falling with that model. If they encounter data contradicting the model (e.g., observations contradicting the notion that heavier objects fall faster), they are likely to keep the model, because it has rich associations with other parts of memory, and discard or distort the data that challenges their views. Because information contradicting their model can be kept in short-term memory without perturbing a model of reality, students can even do well on examinations without any sustained influence on how they understand the world.

Such theories have several important implications. First, students are not likely to change their models, to construct new associations in memory, until they notice sufficient contradictions to existing ones, causing a disequilibrium. Second, because understanding is created by constructing relationships rather than by absorbing or receiving knowledge, the learner is unlikely to disrupt existing models and build new ones without interactive sensory input. Third, students are unlikely to try to build new models unless they attach sufficient significance to the contradictory data; instead, students may simply parrot ideas presented by the teacher to get a better grade without either understanding or believing them. Hence teachers can stimulate the greatest change in students' thinking by putting the students in a situation in which their existing inappropriate models do not work. For example, one can dispel the idea that seasons result from Earth-Sun distance by asking "when it is summer in the U.S., what season is it in Chile?" and by encouraging students to pursue the idea in a variety of contexts and examples until they build new models. Even so, the students must conclude that the problem is significant enough to bother thinking through it. This is perhaps best done when students encounter information in the context of pursuing larger problems and issues that they find intriguing - authentic tasks that arouse curiosity, in which students can try, fail, receive feedback and try again. This process of developing ways to explain data and testing those explanations against other data in the context of solving problems simultaneously instructs students in the use of the scientific method and improves their understanding of basic geological concepts.

This approach might also increase introductory earth science students' interest in the subject. Because few of these students plan to major in earth science, they often take the course because it easily satisfies distribution requirements rather than because they find the topic intrinsically interesting. There is some evidence that addressing preconceptions and teaching specific reasoning skills as part of physics [Shepherd and Renner, 1982] and biology [Purser and Renner, 1983] courses leads to increased enthusiasm for the topic as well as greater mastery of the important concepts. Whether this research can be applied to the tougher audiences in introductory earth science courses is of some interest.

Hence our sense is that we need to know more about what students believe when they enter courses, and how their views are modified by instruction. The latter question is more difficult than the first, and requires careful study. Instructors will need not only to try various teaching methods, but to see how different the results are. One possible conclusion may be

that the traditional broad-brush overview does not concentrate on any topic in enough depth to overcome preconceptions, and that courses with a greater emphasis on a few key concepts do better. This possibility would accord with similar recommendations for elementary and secondary school science classes [AAAS, 1989]. Ultimately, we need to decide what the educational goal of introductory earth science classes is, beyond filling seats to justify faculty and teaching assistant positions.

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