College student conceptions of geological phenomena and their importance in classroom instruction

Julie C. Libarkin

Department of Geological Sciences and Division of Science and Mathematics Education, Michigan State University, US.

The geological sciences have a unique position among STEM (science, technology, engineering, and mathematics) disciplines. While many fields have aspects that are not directly observable, the geological sciences are inherently unobservable for anything except modern, surficial processes. The inaccessibility of geologic time and many processes within the Earth suggests that many student ideas are influenced by events other than observation. Geological understanding may be impacted by several types of experiences, including direct observation, vicarious experiences, and classroom instruction (Table 1).

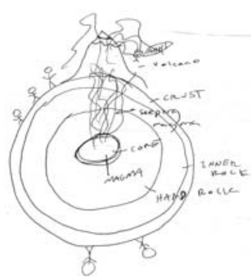
Conceptions research

Student conceptual understanding and the impacts of instruction on student ideas is a burgeoning field of research (e.g., Oliva, 2003). At the college level, significant work has been done in mathematics (e.g., Adams, 1997), physics (e.g., Lewis and Linn, 1994), and chemistry (e.g., Basili and Sanford, 1991), with researchers in biology (e.g., Windscitl and Andre, 1998; Anderson *et al.*, 2002) and geology (e.g., Dodick and Orion, 2003; Libarkin *et al.*, 2005) rapidly catching up to other disciplines.

Assessment of conceptual learning in the geosciences has traditionally focused on K-12 students, with studies of college students or other adults only recently emerging (DeLaughter *et al.*, 1998; Trend, 2000; Libarkin *et al.*, 2005; Dahl *et al.*, 2005; Libarkin and Anderson, 2005). Qualitative studies are mostly concentrated outside of the US (e.g., Happs, 1984; Marques and Thompson, 1997; Trend, 2000; Dodick and Orion, 2003), with those of American students focusing primarily on pre-college populations (Schoon, 1992; Gobert and Clement, 1999; Gobert, 2000). The September 2005 issue of the *Journal of Geoscience Education (JGE)* focused on student conceptual understanding, and provided a significant addition to the literature on conceptions, particularly for higher education geosciences. The wide array of research presented in this issue included both qualitative and quantitative studies, covered topics from radioactivity to climate change to plate tectonics, and is worth review by anyone interested in student alternative conceptions about the Earth. This special issue can be accessed online at: http://nagt.org/nagt/jge/abstracts/sep05.html.

A sharp increase in studies related to conceptual change in college-level physics (see Kurdziel and Libarkin, 2001 for a discussion) has led to significant changes in physics instruction, as well as a new perspective of the importance of physics education research in academic physics (e.g., Gonzales-Espada, 2003). The development of the Force Concept Inventory (FCI; Hestenes *et al.*, 1992) in the early 1990's dramatically changed the way physicists viewed teaching and learning in college level physics courses. Subsequent development of quantitative instruments in other disciplines followed, including developments in biology (Anderson, 2002), physics (Yeo and Zadnick, 2001), astronomy (Zeilik *et al.*, 1999), and the geosciences (Libarkin and Anderson, 2005; Libarkin and Anderson, in press) and can significantly impact the way faculty view classrooms as loci for research. For example, the Geoscience Concept Inventory (GCI) is being used by over 100 faculty for classroom assessment and research. The GCI can be accessed online at: http://newton.bhsu.edu/eps/gci.html.

Table 1. Example experiences that may affect student conceptions.

Type of Experience	Interview or Questionnaire Question	Example College Student Response	Interpretation
Physical	You mentioned that plates pull apart from each other… what happens?	"… I would assume just like you were in a crowd of people ... If we're standing shoulder to shoulder with a bunch of people and some person is pulling and the other person is pushing and I bump into someone else ... something like that, like bumper cars under the Earth."	A physical experience in a crowd or with bumper cars is used to make an analogy to plate motion.
Vicarious	Imagine a giant knife cuts through the Earth. What does the inside of the Earth look like?... Where did your ideas come from?	"I have no clue. I just knew it when I was little, I think that show THE MAGIC SCHOOL BUS. I'm not sure that this is true, I would not bet on it." 	Model is drawn from experiences watching or reading a US television and book series.
Instruction	If you had a time machine and you were able to travel back to the time when the Earth first formed... What do you think the Earth would look like?	"... I think the land would have been one big mass and the rest of the earth would have been more just water surrounding that one big landmass."	In the US, concepts related to supercontinents, such as Pangea, are taught as early as third grade (8-9 year olds).

Revealing student conceptions

Experienced faculty often have a difficult time believing the alternative conceptions held by college students and revealed through conceptions research such as that described above. In my own research I have encountered both science and science educators who believe that college students do not hold the same alternative conceptions as K-12 (US elementary and secondary) students. For example, a geoscientist responded to a question about the Earth's magnetic field by asking,"Is there any rational person who doesn't believe the Earth has a magnetic field?". Our research actually indicated that several of this instructor's students believed the Earth did not have a magnetic field. An even larger number of students believed that magnetism and gravity were related, and thought that the Earth's continents, people, and other objects would float off of the Earth if the magnetic field were shut off. A science educator, in reviewing questions during development of the Geoscience Concept Inventory (GCI: Libarkin and Anderson, 2005; Libarkin and Anderson, in press), believed that a number of questions were much too easy for college students, For example, she believed that college students were well aware that clouds are made up of water, rather than empty containers that are filled with water. In fact, 38% of 997 college students enrolled in entry-level geology courses believed that clouds were empty and filled up with water and/or pollution. This disconnect between faculty perceptions and realities of the models that students are bringing with them to the classroom suggests that identifying and discussing student ideas is a vital part of instruction, as has been suggested by K-12 researchers.

The wide range of topics that fall under the 'geosciences' makes a complete accounting of common student ideas difficult here. Suggestions for how best to elicit student ideas are useful, however, and I provide below several examples from my own research. I personally replicate many of these in my classroom instruction as a springboard for encouraging metacognition in my students and for beginning a discussion about the scientific models I hope to teach. I find it very useful to consider four questions when thinking about student conceptions and instruction: (1) Which concepts in your discipline are considered prior knowledge that students are expected to understand (e.g., gravity)?; (2) Simple questions - do you already or can ask your students about this prior knowledge?; (3) Can you think of any benefit in looking at student responses prior to instruction?; (4) How would responses change your instruction?

Students can be encouraged to think about their own ideas through a variety of techniques, many of which are actually discussed by Angelo and Cross (1993) in their book, *Classroom Assessment Techniques*. Although they don't explicitly encourage the use of these methods for conceptual change and metacognition, these concepts are certainly implicit in the described techniques. I present below a few of these ideas, as an opportunity to both encourage their use in classrooms and share some common conceptions held by students. All of the following techniques can be used to encourage students to think and write on their own, discuss their ideas in small groups and recognize the diversity of ideas among their peers. To encourage students to answer honestly and without fear of being 'wrong', I give credit for completion of the assignment without paying attention to the scientific or non-scientific nature of the students' ideas. In addition, responses to these short questions can be collected and used to build ConcepTest (e.g., serc.carleton.edu/introgeo/interactive/conceptest/motion.html) questions that students can vote on by hand or electronically. This provides an additional forum for discussion. All of the examples given here are drawn from research for which approval for human subjects research was provided by an Institutional Review Board.

Quickie questions. A short question and one minute writing assignment gets students to think about a topic prior to instruction and provides valuable information to faculty. For example, I ask my college students this question: 'What is gravity and what causes gravity?' Students most commonly correlate gravity and magnetism, air pressure, the Earth's rotation, and/or the Earth's position in the solar system. Written answers are generally non-explanatory or illustrate the impact alternative conceptions can have on learning. For example, students have written '9.8 m/s^2', 'Thing that keeps us on Earth', and 'Only Earth has gravity' in response to this question. The latter idea is held by multiple students in every course, suggesting that these students may have difficulty with gravity-related processes like mass wasting to other planets.

Thought experiments. Prior to beginning a new topic, students can be asked to respond to a brief open-ended questionnaire that provides deeper insight into student ideas. Thought experiments that are not necessarily answerable with a right or wrong answer can be very insightful. Notice the wide range of responses to the example question in Table 2. Some students believe that invisibility and non-reflection of light are the same, while other students believe that colour can be correlated to metal content. These data provide information about student thought processes from which an instructor might build a lesson about mining and ore.

Table 2. Example thought experiment question and student responses.

Question	College Student Responses
Tony has a black rock that does not reflect light. Tony breaks the rock open and the inside is exactly the same as the outside. Tony claims he can get iron from this rock. What do you think?	No the rock is invisible. No the rock is coal. No, iron reflects light. Yes, the rock is basalt. Yes, the pieces of iron are too small to see. Maybe, the rock could contain iron.

Drawings. Drawings are a particularly useful method for capturing student ideas, especially in observational sciences like geology. Students are very adept at drawing their models, and this exercise usually takes less than ten minutes, and often as little as one. Drawings are most informative when students are guided towards being as detailed as possible and labeling features. Discussing the drawings in pairs or small groups also helps students recognize the commonalities between their own models and the wide range of models their peers are bringing into the classroom. Before instruction about the Earth's interior, students can be asked the following: If you had a giant knife and could cut the Earth in half, what would the interior look like? Put in descriptive labels; explain technical terms. Put people and volcanoes in the drawing. Why do you believe this model? Where did your ideas come from (imagination, school, books, TV)? The diversity of student ideas documented through this type of exercise is very insightful for designing instruction to target alternative conceptions (Fig. 1).

Figure 1. Examples of student drawings of the Earth's interior.

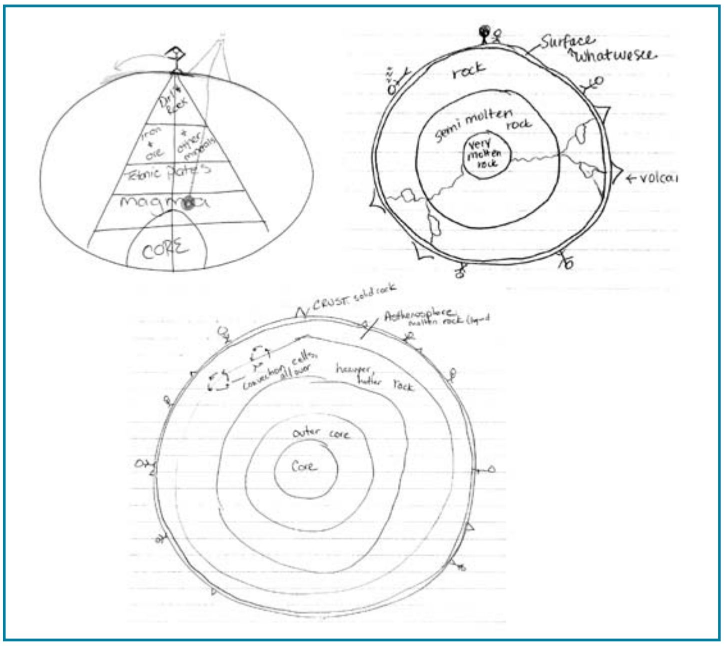
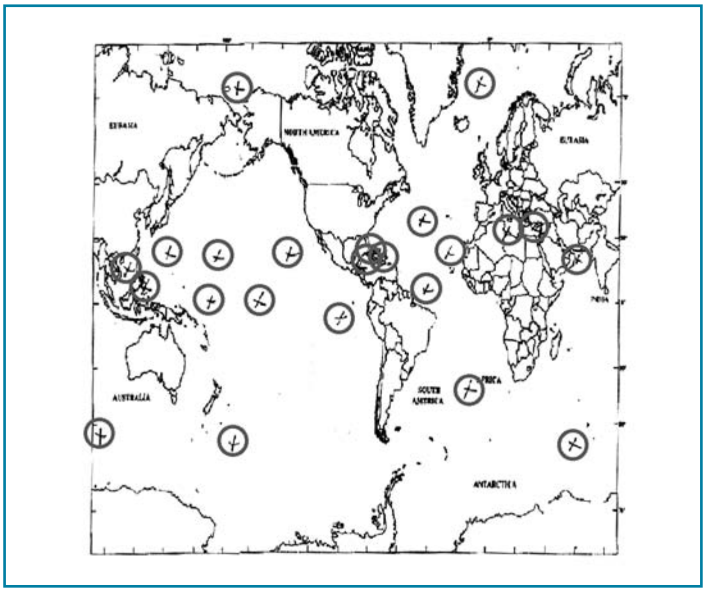


Figure 1(a). Exemplifies a simplistic model held by a small number of students. Notice that the Earth is composed of linear, rather than spherical, layers. In addition, key concepts such as tectonic plates and magma are represented by layers. The core also appears to be at the bottom, rather than the centre of the Earth. Figure 1(b): A more common model of the Earth's interior is represented here. Many US college students believe that lava originates in the Earth's core. This drawing was actually made after instruction on volcanoes, where students were told that magma originates in pools just under the Earth's surface. Notice that this student has blended the center origin and pool origin models. This student has also labeled spherical layers with both compositional ('rock') and physical state ('molten') terms. Figure 1(c): More advanced model held by a few students prior to instruction. Notice that this student has labeled several of the layers with scientific terminology and has provided explanations in some cases. Convection cell processes are also included.

Figure 2 shows an example map of one student's conceptions of global volcano location. Notice that this student places most of the volcanoes along the equator. This student explained this placement by saying, "... a lot of volcanoes are so hot you would think that they would have to occur in a warm area where it would allow it." Instruction about the relationship between tectonic plate boundaries and volcanoes might lead students with this model to believe that the equator is a tectonic plate boundary.

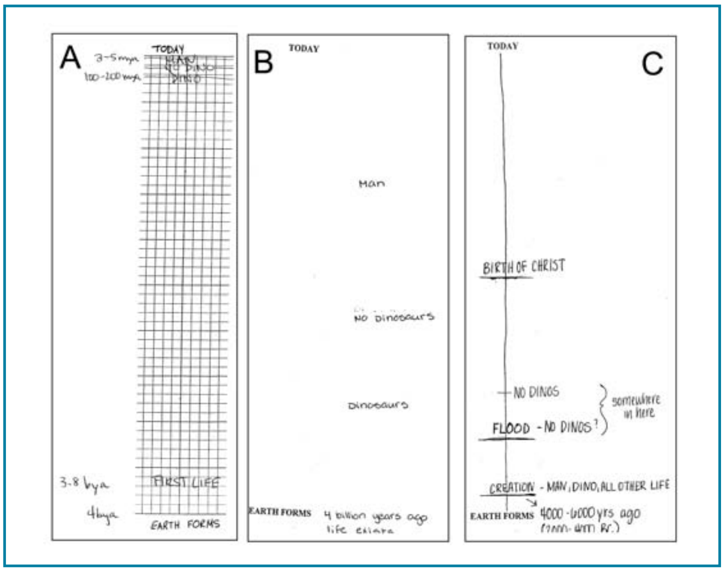
Augmented drawings. In addition to asking students to draw models, students can be asked to augment drawings or maps. This guides students towards certain types of responses and generally

Figure 2. Example map of one student's conceptions of global volcano location.



avoids any confusion that may arise on the part of the student. Geologic or topographic maps, photographs, satellite photos, and cross-sections can all be used in this type of exercise. For example, students can be asked to mark a global map in places where they believe volcanoes occur (Fig. 2), or mark timelines to indicate when various events occurred on Earth (Fig. 3).

Figure 3. Representative student timelines.



(A) Student timeline where absolute dates and relative positioning are both close to the scientific model. This timeline plots very close to the accepted scientific model on both linear and ternary diagrams. (B) Student with mixed scientific and non-scientific ideas. In this case, the student believes that life existed when the Earth first formed. The words "Permian extinction? 50 mya? Not sure" appear next to NO DINOS [Disappearance of dinosaurs] on the original drawing. (C) Student with strict creationist perspective of Earth's history (from Libarkin *et al.*, in press).

Conversations. Interviews with individual students or focus group conversations with multiple students can be conducted by instructors with students in small courses or during office hours, and can take anywhere from five minutes to one hour. Students can also conduct brief interviews with each other during class. Asking general questions and then letting student responses guide further questioning can be particularly illuminating. An example of one elementary-school student (12 years old) provides a particularly exciting example. Two questions, 'What are clouds?' and 'Why does it rain?', served as a starting point for this interview. The student provided a complex cyclic model that illustrated her model of the relationship between cloud structure, rain, and pollution. In brief, she claimed that: (1) Clouds contain both water and pollution; (2) Rain happens when clouds fill up with pollution and become heavy; (3) Pollution is mostly litter (pieces of bags, tissues, cans) that breaks down in water; and (4) Both water and pollution evaporate into the air. Evaporation occurs when wind blows water and pollution into the air. This model explanation prompted another question about the importance of people in the rain process:

> *Interviewer*: If people make pollution, and pollution causes rain, did it rain before people?
>
> *12 year old:* No, I don't think so. When I read books about dinosaurs, they were pretty much before human beings were brought to this world. Usually in books I don't see any clouds, I just see a blank sky, and just the Sun. I never saw any clouds...

This exchange illustrates the valuable information about student models that can be gained from simple conversations with students.

Conclusions

Student alternative conceptions can clearly have a significant impact on how students view natural phenomena, how they reason about natural phenomena, and how they extrapolate to new situations. Faculty should recognize that students are coming to college classrooms with a variety of ideas about both simple and complex phenomena. For example, the fact that most college students would claim that they have learned about gravity or plate tectonics in prior coursework does not mean that they fully understand these phenomena. Using some of the simple techniques described above to elicit student thinking gives instructors an opportunity to encourage students to think about their own ideas. In addition, faculty can create instruction that explicitly targets the alternative conceptions held by their students.

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Professor Julie C. Libarkin: libarkin@msu.edu
Department of Geological Sciences and Division of Science and Mathematics Education, Michigan State University.