Changes in Geologic Time Understanding in a Class for Preservice Teachers

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ABSTRACT

The paradigm of geologic time is built on complex concepts, and students master it in multiple steps. Concepts in Geology is an inquiry-based geology class for preservice teachers at Wright State University. The instructors used the Geoscience Concept Inventory (GCI) to determine if students' understanding of key ideas about geologic time and Earth history changed between the first and last day of the course. For three of the four GCI questions analyzed in this study, the number of correct student responses increased significantly between the pretest and the post-test, indicating that many of the students were learning the concepts being tested. Our analyses indicates that for two of the GCI questions, certain incorrect pretest choices were more likely to give way to correct post-test answers than others. For example, on a question about timelines, students who chose the answer that gave a correct order of events (incorrectly scaled) on the pretest were more likely to switch to the correct answer on the post-test than students who chose an answer with both an incorrect order and scale on the pretest. These results imply that some misconceptions are more likely than others to grow into a correct understanding. Misconceptions that consist of multiple incorrect ideas may require more time and effort to replace than simpler ones. © 2011 National Association of Geoscience Teachers. [DOI: 10.5408/1.3604829]

INTRODUCTION

Modern elementary- and middle-school students are preparing to live in a world of environmental changes including global warming, resource depletion, and extinctions. Earth history is essential for understanding these changes and their ramifications. The idea of continental drift, specifically the reconstruction of Pangea, was essential to the development of the modern understanding of plate tectonics. Similarly, fossils were vital to the development of the theory of evolution, the foundation of modern biology. However, studies of in-service K–8 teachers indicate that they seldom possess adequate content knowledge needed to teach Earth history and geologic time and that they are not confident about teaching these subjects (Trend, 2001; Dahl *et al.,* 2005), which makes it likely that they will avoid teaching them.

At Wright State University, all preservice K–8 teachers take a required ten-week course, Concepts in Geology. The instructors used pre- and post-testing to learn more about their students' initial understanding of Earth history and geologic time when they enter the class, and to determine how and if the course changes that understanding. In order for students to release their hold on their misconceptions, they must abandon or modify older paradigms when confronted with a new model that does not fit with their current mental model (Taber, 2001; Çakir, 2008).

Ideas about the physical Earth that conflict with modern scientific understanding are described as "misconceptions" rather than "alternative conceptions" in this context. The purpose of this study is to help teachers of geology identify and address gaps in their students' knowledge. When students have tried to bridge those gaps using outdated, incomplete, or inappropriate information, then those students have developed misconceptions, which are likely to be expressed through incorrect answers on assessments. The phrase "alternative conceptions" implies that all ideas that students hold about scientific phenomena are valid, whether or not they have any basis in observable reality. In a classroom setting, "alternative conceptions" may be appropriate for rival scientific theories which are currently supported by scientific evidence. On the other hand, "misconceptions" is more fitting for unsupported ideas, such as dinosaurs co-existing with humans or radiocarbon dating being used to establish the age of the Earth. Misconceptions are ideas that instructors help students to dismantle and replace with more scientifically accurate models. Assessment does not always require right and wrong answers, but, at a minimum, instructors need to be able to differentiate between better and worse answers.

Concepts in Geology is intended to build a foundation of knowledge to prepare future teachers for a program of lifelong learning as mandated by their profession. Building this foundation requires students to master threshold concepts and to internalize paradigms that transform the way that they understand science. A threshold concept is an idea or piece of knowledge that, once learned, enables a student to understand potentially important ideas that are alien to their previous experience, conceptually difficult or challenging in other ways (Meyer and Land, 2003). For example, certain problems and processes are hard to understand without an appreciation for the scale of geologic time. The idea that the processes that tore Pangea apart are still operating today is problematic for students who do not know that the Earth is more than ten thousand years old. Such students may instead expect that changes in continental configurations occur abruptly and are driven by catastrophes.

Two of the more difficult threshold concepts that students encounter in geology are the scale of geologic time and the difference between absolute and relative dating (Truscott *et al.,* 2006). Previous studies indicate that when it comes to the geologic timeline itself, college students often put events in the correct order (or close to it), but generally

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have problems determining how far apart events occurred in time (Libarkin *et al.*, 2007). Trend (2000, 2001) argues that college students and in-service teachers clump events into relative-age categories: ancient, less ancient, relatively recent, which helps to order them, but not to remember how far apart they are in time.

Students struggle not only with relative scaling of events, but with the absolute timing of the individual events; they often have no idea how long ago the dinosaurs died or when the Earth formed. College students assign dates to ancient events such as the formation of the Earth and the extinction of the dinosaurs that vary by many factors of ten (Trend, 2000; Catley and Novick, 2009). Catley and Novick (2009) found that students generally underestimate the ages of these events.

Another part of the problem is that the current scientific understanding of the scale of geologic time is based on radiometric dating, a subject poorly understood by most college students, even those that have taken calculus-based physics (Prather, 2005). Misconceptions about Earth history are also widespread, including the idea that there was life on Earth as soon as it formed (Dahl *et al.*, 2005; Libarkin and Anderson, 2005; Libarkin *et al.*, 2005), although many students who expressed this belief describe it as microbial life. Other common beliefs are that the Earth had a single continent when humans first appeared and that dinosaurs appeared about halfway through Earth history (Libarkin and Anderson, 2005).

Concepts in Geology is a combined lecture and lab course that covers rocks and minerals, weathering, water, plate tectonics, geologic time, weather, oceans, and space science. The instructors use hands-on activities, group work, and brief lectures, emphasizing inquiry learning when possible. At the time of this study, much of the assessment took the form of college exams: two mid-terms and a final. The course used a college geology textbook by Tarbuck and Lutgens (2002). According to student responses on a survey question given with the post-test, Concepts in Geology is the first Earth science course that most of them have ever taken. It is also the last Earth science course that most of the preservice teachers who go on to teach K–3 students will ever take. Therefore, it is essential that the lectures, activities, and formative assessments be memorable and understandable so that these preservice teachers can build a foundation for further conceptual understanding.

A number of students in Concepts in Geology have told the instructors that they could not recall having learned about dinosaurs, the ice ages, or other Earth history topics in school at any point. They also mentioned that their inexperience with these topics made them reluctant to teach Earth history. Likewise, both preservice and in-service teachers in a study in the United Kingdom were more reluctant to use open-ended questions and engaging activities to teach Earth history than they were to teach human history (Trend, 2000, 2001). In the United States, religious controversies further complicate efforts to teach state science standards that address geologic time directly, including those dealing with evolution and with the age of the Earth. Only 44% of American adults surveyed believe that human beings are developed from earlier species of animals (Pollack, 2006). Many U.S. high-school biology teachers (36%) reported that they spent 5 or fewer hours on

evolution in general, and 17% never addressed human evolution at all (Berkman *et al.*, 2008). Approximately one in eight reported that they had taught creationist doctrines as scientific theories. Dahl *et al.* (2005) found that many in-service teachers in South Dakota were poorly prepared academically to teach Earth science. These teachers were often uncomfortable even discussing the subject with potential assessors.

This particular study is focused on assessing changes in the students' understanding of geologic time. Rather than memorize lists and schedules of extinct organisms, paleocontinents, ice ages, and sea level changes, the students were encouraged to think of Earth history in terms of cause and effect. They used the present to understand the past in order help develop thinking skills that would be useful in a variety of modern settings. These settings range from the elementary and middle-school classrooms to jury boxes in which these students are likely to serve. Key activities used to teach Earth history included:

- making a plate-tectonics pop-up book,
- a hands-on radiometric dating activity (using candy),
- a field trip to collect fossils,
- two stratigraphic cross-section worksheets, and
- student-developed time-period presentations.

METHODS AND ANALYSIS

The students took a 15-question version of the Geoscience Concept Inventory (GCI), a multiple-choice test developed by Libarkin and Anderson (2005), on the first day of the course. The instructors used the results to sort students into heterogeneous groups with respect to Earth science background (as measured by their GCI scores), in which they worked together for the rest of the quarter. The students took the same test again on the last day of class ten weeks later for extra credit.

A number of studies have been done to establish the validity and reliability of the GCI (Libarkin and Anderson, 2005, 2006, 2008). The distracters for GCI questions are based on answers given by students to open-ended versions of the multiple-choice questions. Over 3500 students in introductory physical and historical geology, oceanography, and environmental science courses at 49 different colleges and universities (including community colleges and a tribal college) took a pretest made up of resulting multiple-choice test items. A variety of geology and education faculty reviewed each question and the responses from students in the test population. The designers discarded questions that yielded results that were biased by gender or other demographic features. The questions were ranked with respect to difficulty using an Item Response Theory (Rasch) analysis so that different but comparable 15-question tests could be assembled and their results transformed into standardized scores.

The sections of Concepts in Geology that were assessed in this study used the same textbook, did the same activities, heard lectures on the same topics, and took similar exams. A total of 108 students in 6 sections (1 per quarter from September 2005 through November 2006) completed all questions on both the pre- and the post-test and consented to be part of the study. All of the students were undergraduates majoring in Early Childhood Education (preparing to teach preschool through third grade) or

Middle Childhood Education (preparing to teach fourth through ninth grade). Most students were Caucasian and of traditional college age. Few had taken a college-level geology course, but the prerequisites for Concepts in Geology include a physics course and a science methods course. No personal information was kept on any student except for that collected for the purposes of teaching the class.

Three different instructors and four different teaching assistants taught these sections of Concepts in Geology, but all were experienced at teaching geology by inquiry. The instructors were all faculty in the Department of Geological Sciences, each having a Ph.D. in geology or a related scientific field. Class sizes varied from 5 to 28 students per section. Analyses of variance (ANOVA) for differences by instructor and by class on the students' overall standardized GCI pretest and post-test scores, and the normalized score gains revealed no differences at the 5% level of significance (Table I). In fact, p was greater than 0.39 for all of these analyses, indicating that differences between sections, including class size and instructor, had a trivial effect on GCI pretest and post-test scores and normalized gains between the two. These statistics indicate that students' initial geology backgrounds did not vary significantly between different sections, nor did their learning gains. Therefore, responses from students in all six sections were included in this study.

Four of the questions on this GCI version address geologic time or Earth history directly. An increase in the number of correct answers on the post-test relative to the pretest, taking into account the large-sample (n ≥ 108) 95% confidence interval for a population proportion, presumably indicate improved average student understanding of a particular concept. However, learning can take many forms, and it could be a matter of learning which answer is likely to be right or learning to recognize particular answers as wrong.

McNemar's chi-square test of the difference of paired proportions determined directionality of changes in answers. If answer changes from pre- to post-test are completely random (H_0), the number of students that switch from a wrong answer on the pretest to the correct one on the post-test would be approximately equal to the number that switch from the correct answer on the pretest to a wrong one on the post-test.

RESULTS

The questions in the GCI tend to be complex and require critical thinking rather than memorized knowledge. Rather than ask students how old the Earth is, for example, all versions of the GCI ask which techniques scientists use to determine the age of the Earth (question 1; Fig. 1). Analysis of this particular question was difficult because students could choose "all that apply." To give a completely correct response (C; only C), students need to know not only the applications of different kinds of radiometric dating (radiocarbon versus uranium-series) but also to recognize types of relative dating and why they are inappropriate in this case.

TABLE I: ANOVA test for differences in total GCI standardized scores (pretest, post-test, and normalized gain) between instructors and between individual classes. None of the sections differ significantly for any of the measures (0.39 < p < 0.75), nor do the sets of students taught by the various instructors (0.66 < p < 0.85).

ANOVA for differences by instructor

Instructor	N	Pretest		Post-test		Normalized gain	
		Mean	Variance	Mean	Variance	Mean	Variance
1	19	37.81	123.96	47.73	118.47	0.14	0.040
2	24	36.31	192.08	47.15	116.41	0.15	0.039
3	65	38.83	115.18	49.57	149.35	0.17	0.035
F statistic		0.42		0.46		0.163	
p-value		0.66		0.63		0.85	
numerator degrees of freedom = 2				denominator degrees of freedom = 105			

ANOVA for differences by class

| Class ID	N	Pretest		Post-test		Normalized gain	
		Mean	Variance	Mean	Variance	Mean	Variance
10611	25	37.16	97.91	47.29	189.55	0.15	0.041
10641	24	36.31	192.08	47.15	116.41	0.15	0.037
20611	17	37.04	120.51	51.47	114.78	0.21	0.040
20631	19	37.81	123.96	47.73	118.47	0.15	0.034
30511	5	46.16	218.19	57.52	214.33	0.22	0.027
30611	18	40.80	103.41	50.90	126.56	0.13	0.024
F statistic		0.87		1.05		0.535	
p-value		0.50		0.39		0.749	
numerator degrees of freedom = 5				denominator degrees of freedom = 102			
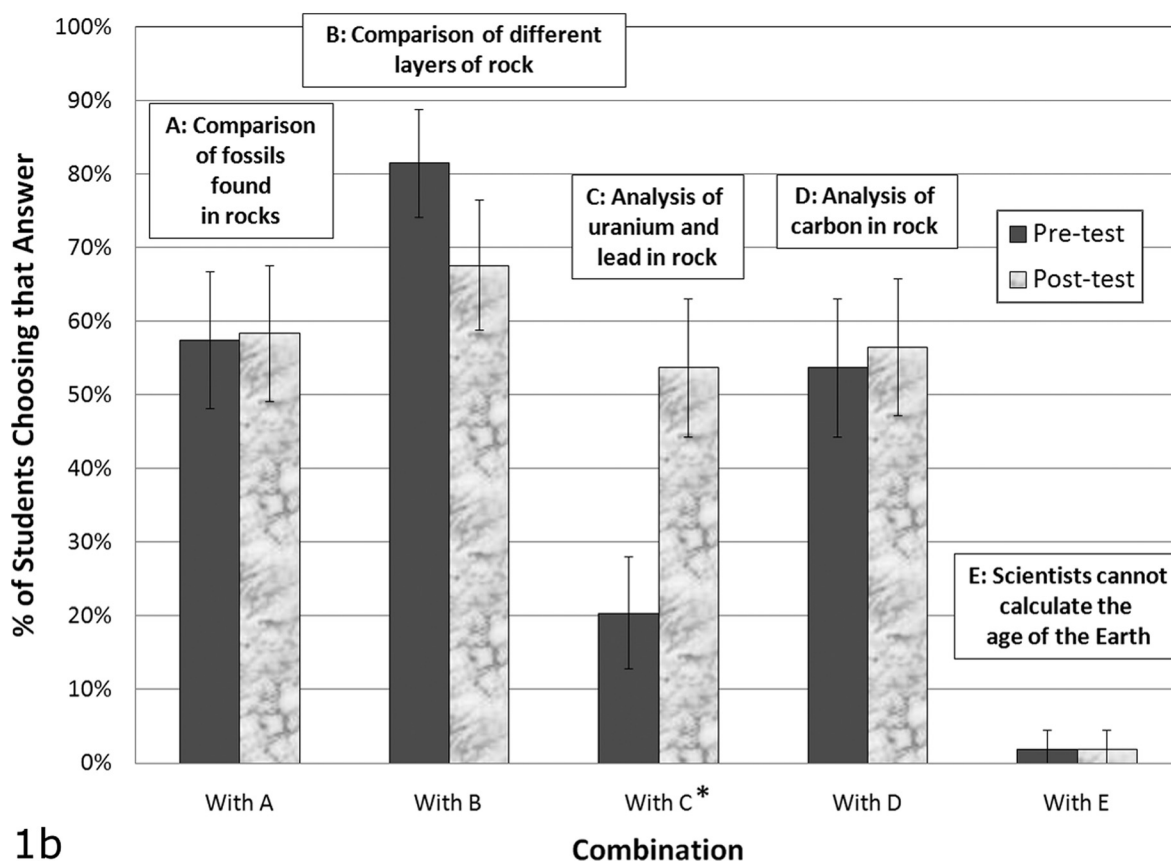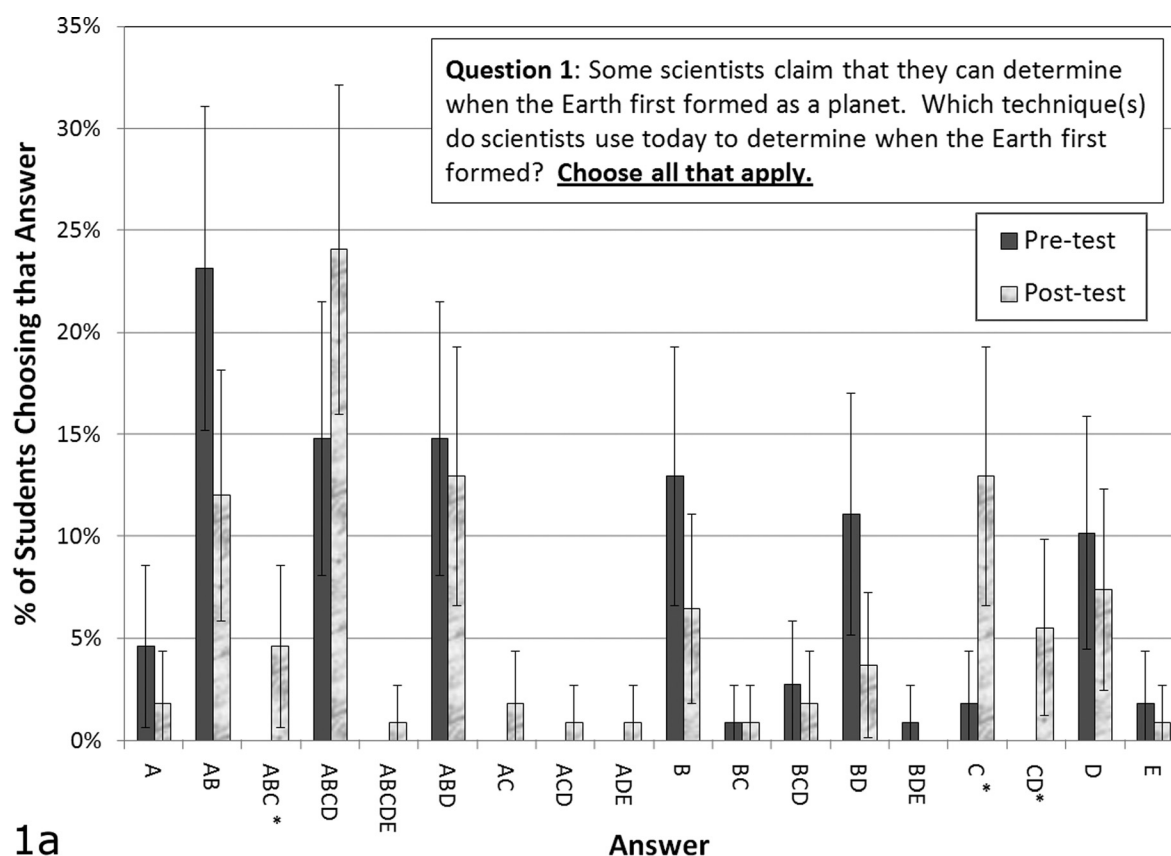
FIGURE 1: (a) Histogram of student responses to question 1. Error bars represent a 95% confidence interval. Asterisk marks nonoverlapping 95% CIs between pre- and post-test proportions. (b) Histogram of combinations of student answers to question 1. Error bars represent a 95% confidence interval. Asterisk marks nonoverlapping 95% CIs between pre- and post-test proportions.

> **1.** Some scientists claim that they can determine when the Earth first formed as a planet. Which technique(s) do scientists use today to determine when the Earth first formed? **Choose all that apply.** (Q1)
>
> (A) Comparison of fossils found in rocks
> (B) Comparison of different layers of rock
> (C) Analysis of uranium and lead in rock
> (D) Analysis of carbon in rock
> (E) Scientists cannot calculate the age of the Earth

Two of 108 students gave the correct answer on the pretest [Fig. 1(a)]. The number of correct answers increased significantly from 2% on the pretest to 13% on the post-test (based on 95% confidence intervals). According to Item Response Theory measurements, question 1 is the most difficult question in the GCI pool (Libarkin and Anderson, 2006). The 13 students in this sample who changed their answers from incorrect answers on the pretest to correct answers on the post-test had significantly higher overall pretest scores on average (mean = 43.53) than the 94 (mean = 37.03) who answered incorrectly on both the pre- and post-tests (Table II).

Combinations of answers that include "C" are partly correct, and the number of students choosing "C"-combination answers increased from 20% to 54% [Fig. 1(b)], a significant increase (McNemar's test of paired proportions, p < 0.0001). Petcovic and Ruhf (2008) saw a nearly identical increase in combinations including "C" on the GCI before and after a similar teacher-education course that they had revised based on previous GCI results. The number of correct answers increased significantly from 2% on the pretest to 13% on the post-test (based on 95% confidence intervals).
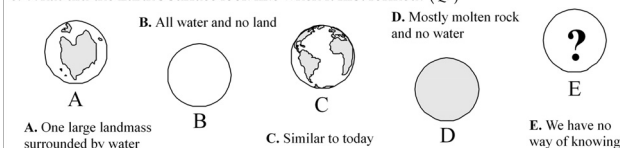
> **4.** If the single continent in #3 did exist, how long did it take for the single continent to break apart and form the arrangement of continents we see today? (Q37)
>
> (A) Hundreds of years
> (B) Thousands of years
> (C) Millions of years
> (D) Billions of years
> (E) It is impossible to tell how long the break up would have taken

Question 37 deals with the rate of plate motion and the history of Pangea (Fig. 2). The number of students who chose the correct answer ("C") increased (from 42% to 56%) between the pretest and the post-test [Fig. 2(a)]. The 95% confidence intervals in Fig. 2(a) overlap because almost half of the students who had chosen the correct answer "C: millions of years" on the pretest changed their answer to a wrong one on the post-test [Fig. 2(b)]. However, McNemar's test of the difference of paired proportions indicates that the pattern of change in the answers was not random. The large number of students who switched from the correct answer on the pretest to the wrong answer on the post-test was significantly smaller (p < 0.029) than the number of students who switched from the wrong answer on the pretest to the correct answer on the post-test. "B:

thousands of years" declined visibly in popularity from the pretest to the post-test responses [Fig. 2(a)].


> **6.** What did the Earth's surface look like when it first formed? (Q7)
> **B.** All water and no land   **D.** Mostly molten rock and no water
> A   B   C   D   E
> **A.** One large landmass surrounded by water   **C.** Similar to today   **E.** We have no way of knowing

Most students [61% on the pretest and 59% on the post-test; Fig. 3(a)] chose "A" —an image of Earth with a single visible continent (which some may have believed to be Pangea) when asked what the Earth's surface looked like when the Earth formed (question 7). Interestingly, 75% of those who chose that image on the pretest also chose it on the post-test, so it is likely that most were certain of their answer from the outset [Fig. 3(b)]. The proportion of students choosing the correct answer ("D") did not change significantly between the pre- and post-tests (from 9% to 13%; p = 0.250 for McNemar's test). Relatively few students changed their answers to question 6 between the pre- and post-test [Fig. 3(b)] compared to the other questions.

> **11.** Which of the figures below do you think most closely represents changes in life on Earth over time? (Q28)
>
> Choose one: **A   B   C   D   E**
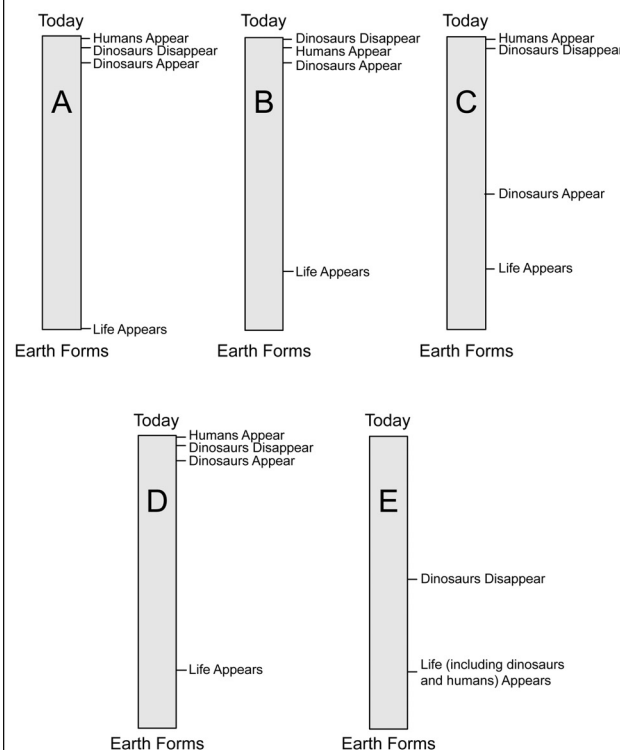
One of the most complex questions (question 28) involves choosing the correct timeline of Earth history

TABLE II: ANOVA test for differences in GCI-pretest standardized score between students who changed their answer to no. 1 from an incorrect answer on the pretest to the completely correct answer on the post-test and students who had an incorrect answer on no. 1 for both pre- and post-test. The first group (changed to a correct answer) had a significantly higher mean pretest score than the group that chose partly and completely incorrect answers.

ANOVA for differences by post-test no. 1 answer			
Answer to question no. on post-test	N[a]	Pretest	
		Mean	Variance
Correct (C)	13	43.53	89.28
Incorrect or partially correct	94	37.03	126.19
F statistic	3.96		
p-value	0.049		
numerator degrees of freedom = 1			
denominator degrees of freedom = 105			

[a]One student was not in either group, answered no. 1 correctly on both pre- and post-test.

(Fig. 4). All choices start with the formation of the Earth, but the order and scaling of the appearance of life, dinosaurs, and humans, and the disappearance of the dinosaurs, varies [Fig. 4(a)]. The number of students who chose the correct timeline, "D" (from 18% to 40%, p < 0.0002) increased substantially and significantly between the pretest and the post-test. Students who chose certain incorrect answers, "A" and "C," on the pretest were more likely (50% or 41%) than students who chose "B" or "E" on the pretest (20% or 25%) to give the correct answer "D" on the post-test [Fig. 4(b)].

INTERPRETATIONS

Significant increases in the number of right answers between the pre- and post-test for three of the four questions on geologic time and Earth history indicate learning gains in Concepts in Geology. However, even those students who changed their response from one wrong answer to another may have learned something, just not enough to answer the question completely. Several models of learning describe misconceptions as temporary models that will allow learners to make the transition to a scientifically valid understanding (Linn and Muilenberg, 1996; Hamza and Wickman, 2008; Steedle and Shavelson, 2009), as well as those that describe a partial understanding based on correct ideas that cannot be generalized (Clement *et al.*, 1989; Taber, 2001).

GCI questions tend to be complex, involving multiple concepts at once. If misconceptions are partially correct ideas constituting a transitional stage in learning, some will be more correct than others. For example, to answer question 1 correctly, students must not only know that uranium-lead dating is an appropriate tool for dating the age of the Earth, they must also know that the other techniques listed are inappropriate. They need at least four different pieces of knowledge to discount the incorrect answers. A few students in Concepts in Geology (13 of 108) made enough progress during the course to answer the question correctly on the post-test, but these came into the class with a stronger Earth science background than many of their colleagues as measured by the GCI.

The preservice teachers taking Concepts in Geology [Fig. 1(b)] and a similar class studied Petcovic and Ruhf (2008) were more likely to choose combinations including "C," the correct answer, on the post-test than on the pretest for question 1. Radiometric and relative dating were covered in the text and in lecture during Concepts in Geology, and the concepts were reinforced with hands-on exercises. The limits of each kind of dating were explicitly described. About a third of the students added uranium-dating to their list of geologic age-measurement techniques between the pre- and post-test. One interesting problem remaining to be investigated is why so few students include uranium-lead dating in their pretest answers.

Question 37 also appears to test multiple conceptions, not all of them geologic. It asks how long an ancient supercontinent took to break up. First, students need to have some idea of the magnitude of the numbers in the selection of potential answers in order to fully understand the rate of plate motion at a continental scale, and studies show that college students often struggle with basic mathematics (Standing, 2006; Seaman and Szydlik, 2007). In particular, proportional reasoning (Sowder *et al.*, 1998; Berk *et al.*, 2009) and large numbers are difficult for many preservice teachers. When students in a recent section of Concepts in Geology were asked how many thousands were in a million, only 10 out of 17 were able to answer correctly. How are the remaining seven to distinguish between millions and billions of years? This may explain why 33% of the students who answered correctly ("millions of years") on the pretest switched their answers to "billions of years" on the post-test [Fig. 2(b)]. The student-researched time-period presentation project may have contributed considerably to the reduction of "B" answers on the post-test. During those presentations, the students described their time periods in terms of duration (in millions of years).

The other problem may be related to the misconception revealed by responses to question 7, what the Earth looked like when it first formed. The misconception that Pangea was present when Earth first formed is powerful. It remained intact in most cases despite the work the students did in class [Figs. 3(a) and 3(b)], or possibly because of it, since Pangea was discussed in both the plate tectonics and the Earth history units. The topic of Pangea generally gets a whole page in each student's plate-tectonics pop-up book, whereas the correct model of the earliest Earth as completely molten, answer "D," only appears as a single slide in a lecture on the Precambrian and is not mentioned in the textbook. Paleozoic time-period presentations almost all covered the assembly of Pangea, which conflicts with the model of Earth starting with Pangea. The field trip also emphasized the importance of the Paleozoic, since the fossils that the students collected were Ordovician and Silurian in age. The students may have developed multiple, incompatible models of Earth history, and refer to different models for different questions (Taber, 2000).

If students believe that Earth history begins with Pangea and remember that the Earth is billions of years old, they would logically deduce that it took billions of years for Pangea to break into modern continents. However, this explanation does not explain the distribution of answers on the post-test. Students who gave the correct answer to question 7 on the post-test, that the Earth was molten when it formed, were slightly more likely to answer
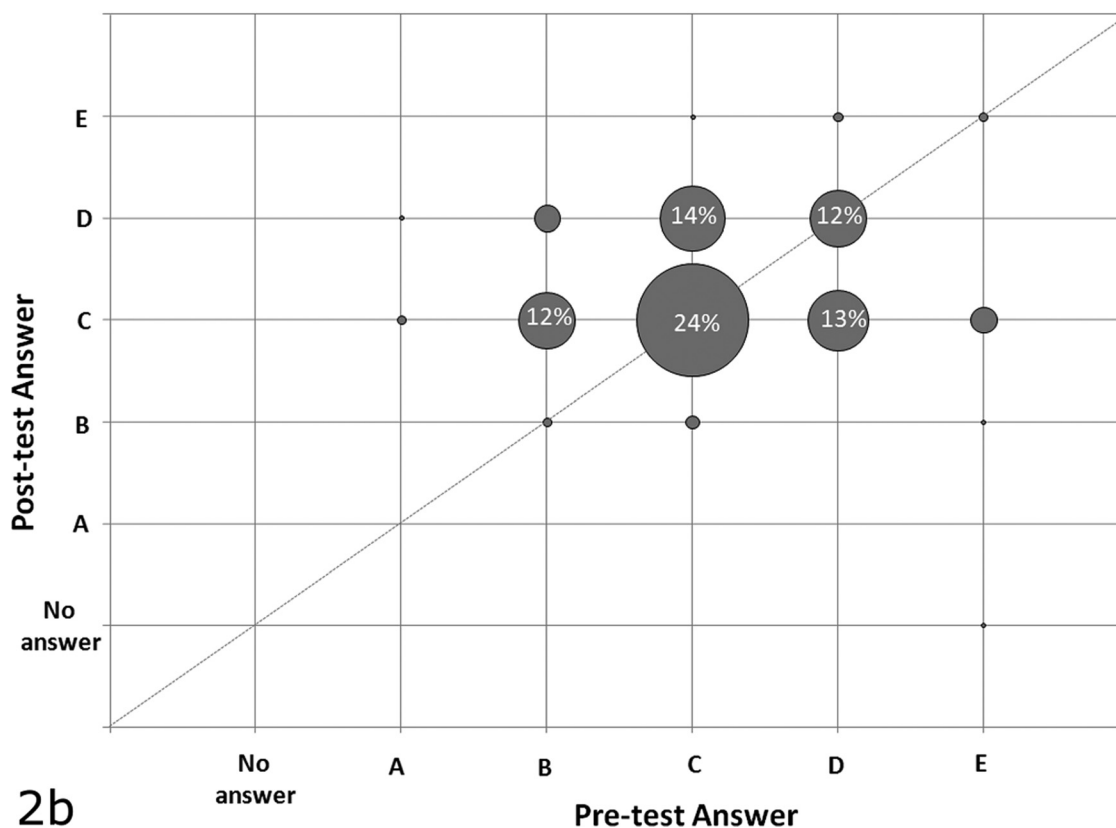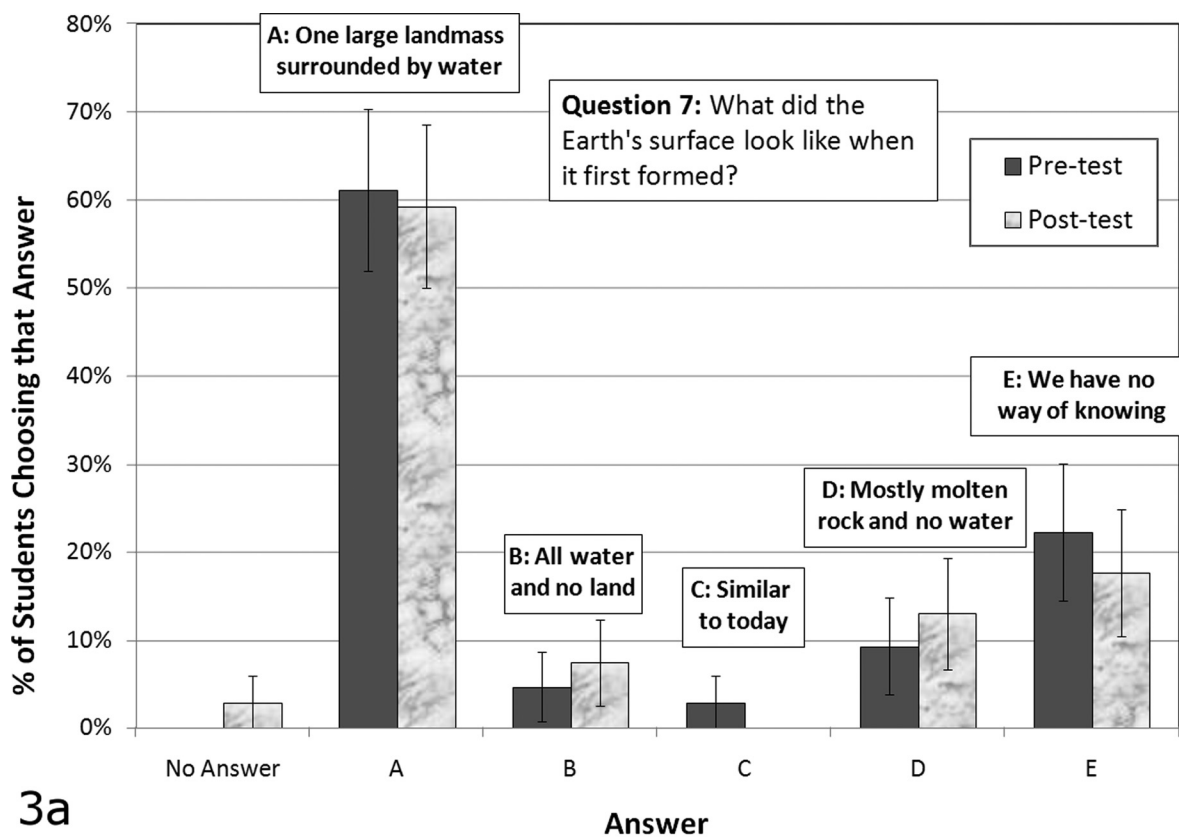
2a

2b
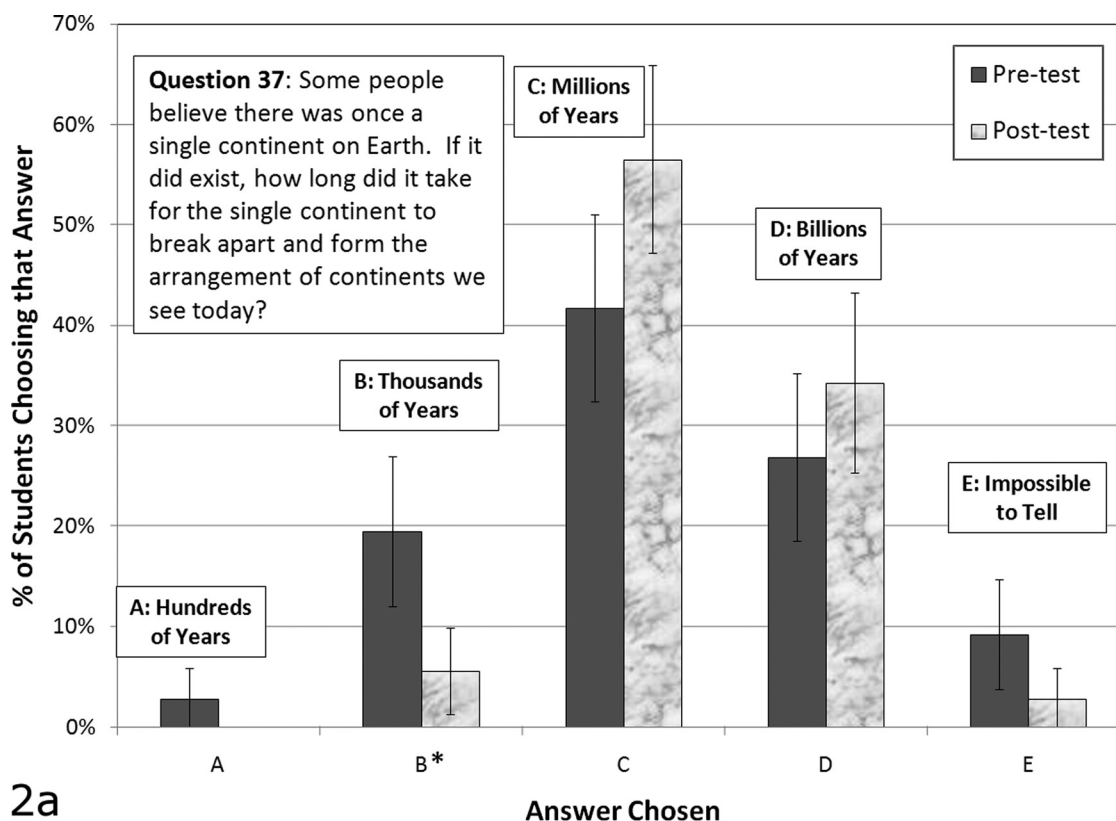
FIGURE 2: (a) Histogram of student responses to question 37. Error bars represent a 95% confidence interval. Asterisk marks nonoverlapping 95% CIs between pre- and post-test proportions. (b) Bubble plot of student pretest vs post-test responses to question 37. Bubble diameter is proportional to the number of students choosing a given pair of answers. Percentages are shown for all answers.
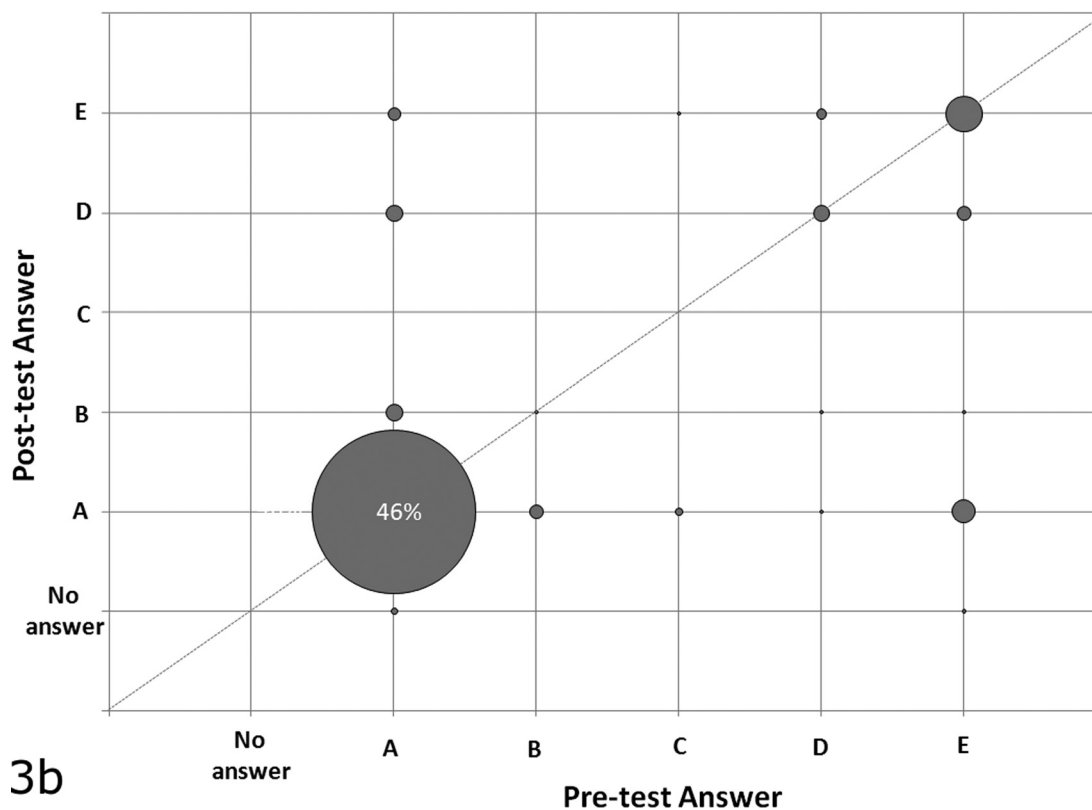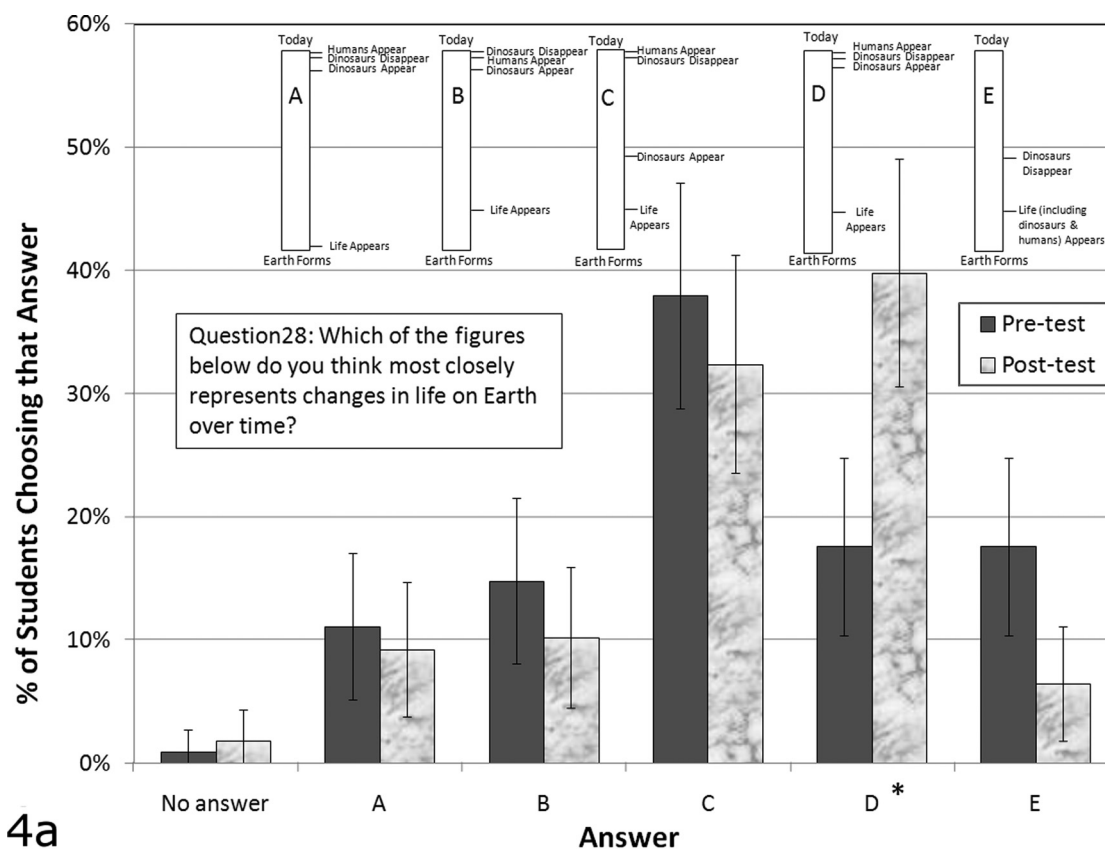
3a

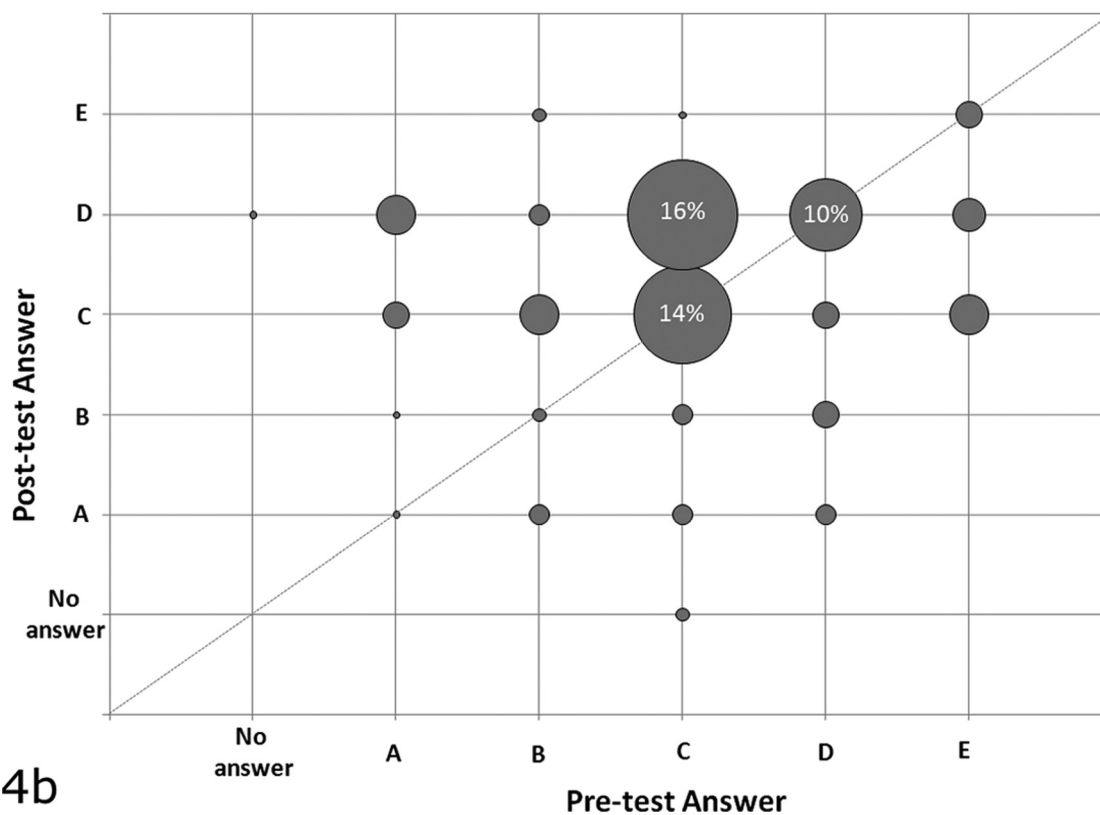**Pre-test and Post-test Answer Combinations for Question 7**

3b

FIGURE 3: (a) Histogram of student responses to question 7. (b) Bubble plot of student pretest vs post-test responses to question 7. Bubble diameter is proportional to the number of students choosing a given pair of answers. Percentages are shown for all answers.

4a

Pre-test and Post-test Answer Combinations for Question 28

4b

FIGURE 4: Histogram of student responses to question 28. Error bars represent a 95% confidence interval. Asterisk marks nonoverlapping 95% CIs between pre- and post-test proportions. (b) Bubble plot of student pretest vs post-test responses to question 7. Bubble diameter is proportional to the number of students choosing a given pair of answers. Percentages are shown for all answers.

"billions of years" to question 37 than students who chose the image of a single continent for question 7. How many students think that the single continent is Pangea, and how old do those students believe the Earth to be?

The best evidence for "better" and "worse" misconceptions comes from the student responses to question 28 [Fig 4(a)]. The four incorrect timelines vary in the number and type of errors that they exhibit. Answers "A" and "C" are timelines with events in the correct order, but each with a single scaling error. Timeline "B" has two events out of order. Timeline "E" has fewer events than the others, but multiple errors of both order and scale.

Overall, the whole student population shows evidence of learning because the number of completely correct answers increased [Fig. 4(a)]. Students who chose the correct timeline, "D," on the pretest, usually (58%) also chose it on the post-test [Fig. 4(b)]. Those who chose "A" and "C" on the pretest were more likely to choose "D" on the post-test than they were to choose any other timeline, including their pretest preference. These students showed an increased understanding of the relative timing of these events. Students who chose "B" on the pretest were twice as likely to choose "C" on the post-test as they were to choose any other timeline. Students who chose "E," the timeline with the most errors, were also more likely to choose "C" on the post-test, but not by as wide of a margin. In this case, it appears that students usually work out the order of events on the timeline before they develop an understanding of the scaling, as proposed by Libarkin *et al.* (2007). Scaling is probably a difficult issue for the students who were struggling with large numbers and proportional reasoning.

IMPLICATIONS FOR TEACHING

The class Concepts in Geology involves inquiry-based student-centered learning, with multiple representations of the material. However, in a class with so many topics to cover, student activities are often rushed. In 2005–2006, one 2.5 h class was spent on a field trip, another class on stratigraphy and dating, and a third class on time-period presentations (which were prepared outside of class). Furthermore, the textbook (Tarbuck and Lutgens, 2002) has two chapters on geologic time.

A more judicious mix of brief lectures, demonstrations, activities, and guided inquiry may help students get more out of the course by building their science content and pedagogical content knowledge, and cover topics that the course activities do not presently address explicitly. Petcovic and Ruhf (2008) found that students were more likely to improve their performance on GCI questions on topics that were addressed by classroom activities than on those dealt with only in reading and in discussion. The Precambrian presents an unusual problem; it is covered by an instructor's presentation, but there is still no time for a student research project in addition to the time-period presentation.

Concepts in Geology was redesigned in 2007 to spend more time on plate tectonics and geologic time as a result of the analysis of the GCI results. Students now do an exercise in which they draw a scaled timeline of events chosen from their own lives and another of listed geologic events. This project was originally used in a 2004 version of Concepts of Geology to help students connect old and new information and to teach scaling to students who have trouble with it. It explicitly emphasizes math and proportionality and explores the reasons for the emphasis on relatively recent events in Earth history. When a similar personal-timeline exercise was added to an introductory geology class for preservice teachers at another institution, the students increased the number of correct answers on question 28, about the geologic timeline from 45% to 55% (Petcovic and Ruhf, 2008).

Throughout the revised geologic-time unit in Concepts in Geology, the instructor shows twenty-minute episodes of "Chased by Sea Monsters" (Impossible Pictures, 2004). This video tells a story about a time-traveling zoologist who visits the seven deadliest seas of the Phanerozoic era (each in a different time period) and features charismatic extinct megafauna that are not dinosaurs. Students take notes using a worksheet. Many of the organisms depicted lived either before or after dinosaurs (helping students envision pre-dinosaur prehistory). The instructor stops between time periods to discuss with the students where each time period is relative to one another (since the time travelers are not visiting the seas in chronological order) and to discuss uniformitarianism (in this case, inferring the behavior of extinct animals from modern ecological analogs).

CONCLUSIONS

In many cases, students in Concepts in Geology embrace significant misconceptions about geologic time and Earth history. The course did not enable most of the students to overcome the misconception that the Earth first formed with a single landmass. More than half of them had given presentations on Paleozoic time periods, and most of those had mentioned the assembly of Pangea, and all of them had collected Paleozoic fossils. A significant number of students revised their estimates of how long it took Pangea to break up to millions of years. The misconception that the breakup took thousands of years proved easier to displace than the misconception that it took billions of years.

The number of correct answers about how the scientific community measures the age of the Earth increased significantly. However, the students who switched from incorrect answers on the pretest to correct ones on the post-test had higher pretest GCI averages than the rest, indicating a stronger-than-average Earth-science background. Even students who answered incorrectly were more likely to incorporate the correct answer into their post-test answers than they were on their pretests. At least Concepts in Geology enabled them to recognize uranium-lead dating as "a" right answer, though it did not help them to eliminate all of the incorrect answers.

The number of students who chose a correctly scaled and ordered timeline of the history of life on Earth increased substantially and significantly between the beginning and the end of Concepts in Geology. Students who initially chose a correctly ordered but incorrectly scaled timeline were more likely to choose the correct one on the post-test. Students who chose a timeline with events out of order on the pretest were likely to choose an incorrectly scaled, but correctly ordered timeline, on the post-test. So if students enter Concepts in Geology already knowing the

order in which important events occurred, they were often able to learn roughly how far apart in time those events occurred. If students joined the class confused about the order, they generally did learn the order but rarely learn how the events were spaced in time.

As a multiple-choice test, the GCI is easy to administer to large numbers of students, easy to score, relatively easy to analyze, but can be difficult to interpret. The available distracters were treated as representing misconceptions, but it was not possible to determine why students chose various distracters at the start at the end of the course based on the GCI results themselves. Some of the distracters, when chosen on the pretest, were more likely to be replaced by the correct answer on the post-test than others, indicating that the misconceptions that they represented were less of an impediment to learning, or that they represented partially developed correct conceptions.

Education majors in another science course at Wright State University are participating in a study that asks them to explain the reasoning behind their choice of answers on a truncated version of the GCI. In at least one future section of Concepts in Geology, students will work in homogeneous groups for the geologic-time unit based on their responses to the question about changes in life on Earth over time (question 28). Students who answered "B" or "E" on the pretest will get extra help, which will give the instructor an opportunity to chart individual learning with respect to issues like sorting and ordering of events and scaling between them.

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