Increasing Learning in Introductory Geoscience Courses Using Lecture Tutorials

Karen M. Kortz — Community College of Rhode Island, Physics Department, 1762 Louisquisset Pike, Lincoln, RI 02865, kkortz@ccri.edu; and University of Rhode Island, Department of Geosciences, Woodward Hall, Kingston, RI 02881

Jessica J. Smay — San José City College, 2100 Moorpark Avenue, San José, CA 95128, jessica.smay@sjcc.edu

Daniel P. Murray — University of Rhode Island, Department of Geosciences, Woodward Hall, Kingston, RI 02881, dpmurray@uri.edu

ABSTRACT

Students often leave introductory geoscience courses without learning the scientific perspective, and we developed Lecture Tutorials to help alleviate this problem. Lecture Tutorials are 10-20 minute interactive worksheets that students complete in small groups in class after a short introductory lecture. They are specifically designed to combat alternative conceptions and increase learning on difficult topics. Our study shows that Lecture Tutorials increase student learning in the classroom more than just lecture alone. On related multiple choice questions asked before and after the Lecture Tutorial (but after a short lecture on the topic), student scores increased 19%. When a subset of these questions was given before and after an extended lecture instead of a Lecture Tutorial, student scores did not increase by a statistically significant amount. On the multiple choice assessment questions given on exams relating to the information covered in the Lecture Tutorials, students who completed the Lecture Tutorials scored significantly higher than students who heard just lecture. In addition, students feel that they are an important and useful part of their learning experience. Lecture Tutorials are being disseminated and are available for instructor use.

INTRODUCTION

Students do not enter geoscience courses as a blank slate, but instead enter with prior knowledge and understandings as to how the Earth works. Some of this knowledge is accurate, and some is not. The non-scientific and incorrect explanations (called alternative conceptions here after Libarkin (2005) but also known as misconceptions) do not match the scientific way of thinking (Anderson et al., 2002; Libarkin, 2005). Unfortunately, students leave introductory geoscience courses with many of these alternative conceptions still intact (Libarkin and Anderson, 2005; Libarkin et al., 2005). Many geoscience instructors do not recognize that their students have not learned the scientific perspective until it is too late (e.g. the final exam).

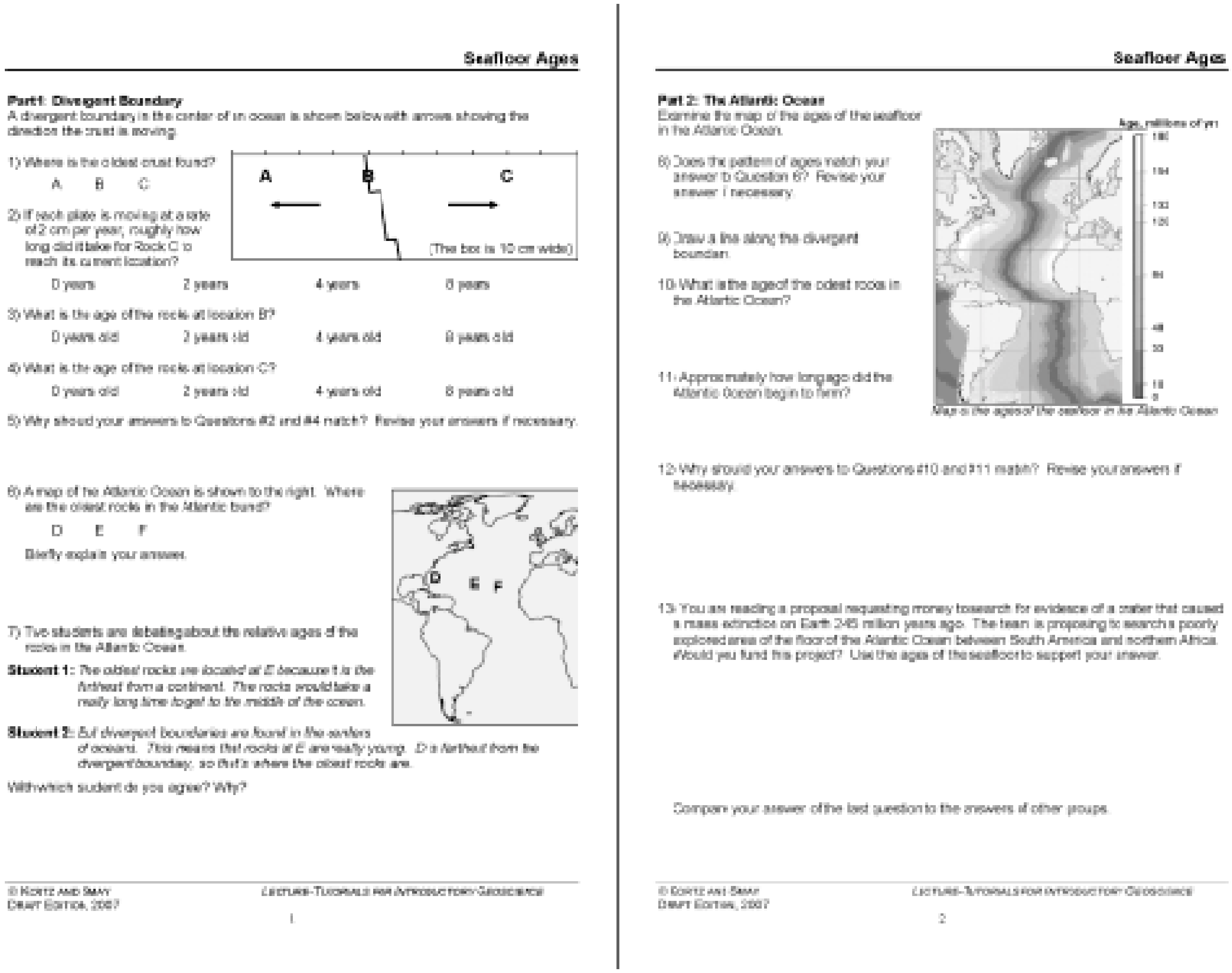
Students cannot learn the scientific way of thinking if they continue to fall back on their alternative conceptions (Clement, 2000; Gobert, 2000; Taber, 2003). In order to promote conceptual change in students, the instructor must create an environment in which the students confront their alternative conceptions, learn why these ideas must be rejected, and then build a new understanding of how the world works (Hewson and Hewson, 1988; Dreyfus et al., 1990; Chan et al., 1997). Research has shown students can abandon their alternative conceptions if they are shown that their beliefs conflict with scientific data (Posner et al., 1982), but additional knowledge-building activities need to be employed to produce a true conceptual change (Jensen and Finley, 1995; Chan et al., 1997, Chinn and Brewer, 1998, Guzzetti, 2000).

Studies show that traditional lecture-style classes may not be as effective in improving student learning as more student-focused classes (e.g. Hake, 1998; National Research Council, 2000; Crouch and Mazur, 2001; Chiu et al., 2002; Meltzer and Manivannan, 2002; McConnell et al., 2003; Steer et al., 2005). As a result, alternative conceptions are often left intact after a student listens to lecture.

However, using alternatives to lecture may not automatically increase student learning (Hake, 1998; Libarkin and Anderson, 2005; Kirschner, 2006). Libarkin and Anderson (2005) found no correlation between self-reported teaching style and student performance on questions measuring conceptual understanding. Also, minimally guided instruction (such as constructivist, problem-based, and inquiry-based teaching) has also been shown to be less effective and efficient than approaches that strongly guide the student learning process, such as direct instruction (Kirschner et al., 2006; Sweller et al., 2007).

Kelso and others (2000) and Macdonald and others (2005) found that most geoscience instructors use lecture as their primary method of teaching. Lecture understandably often becomes the default teaching method because instructors do not have the time to dedicate to altering their classes or to become familiar with recent developments in pedagogy, or they do not believe alternative teaching methods are effective. As importantly, there are often strong incentives placed on teachers to cover all the chapters in the book, which precludes teaching strategies that do not rely heavily on lectures. Finally, many of the current approaches to decreasing the amount of lecture in the classroom work very well in small classes but are not as useful in large classes.

Many methods are being developed and used to increase interactive learning in geoscience classrooms, large and small. For example, Conceptests are conceptually based multiple-choice questions that are posed, voted on, discussed, and voted on again by students during lecture (Mazur, 1997; Crouch and Mazur, 2001; McConnell et al., 2003; McConnell et al., 2006). Other techniques for interactive learning include Question of the Day, Gallery Walks, Jigsaw Groups, Think-Pair-Share, and Debates (e.g. King, 1993; Tewksbury, 1995; Reynolds and Peacock, 1998; McConnell et al., 2003; Libarkin, 2006; Science Education Resource Center, 2007). All these techniques promote interaction, but several studies have shown that making


Seafloor Ages

Part 1: Divergent Boundary
A divergent boundary in the center of an ocean is shown below with arrows showing the direction the crust is moving.

1) Where is the oldest crust found?
A B C

2) If each plate is moving at a rate of 2 cm per year, roughly how long did it take for Rock C to reach its current location?

0 years 2 years 4 years 8 years

3) What is the age of the rocks at location B?
0 years old 2 years old 4 years old 8 years old

4) What is the age of the rocks at location C?
0 years old 2 years old 4 years old 8 years old

5) Why should your answers to Questions #2 and #4 match? Revise your answers if necessary.

6) A map of the Atlantic Ocean is shown to the right. Where are the oldest rocks in the Atlantic found?
D E F
Briefly explain your answer.

7) Two students are debating about the relative ages of the rocks in the Atlantic Ocean.

Student 1: *The oldest rocks are located at E because it is the farthest from a continent. The rocks would take a really long time to get to the middle of the ocean.*

Student 2: *But divergent boundaries are found in the centers of oceans. This means that rocks at E are really young. D is farthest from the divergent boundary, so that's where the oldest rocks are.*

With which student do you agree? Why?

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Seafloor Ages

Part 2: The Atlantic Ocean
Examine the map of the ages of the seafloor in the Atlantic Ocean.

8) Does the pattern of ages match your answer to Question 6? Revise your answer if necessary.

9) Draw a line along the divergent boundary.

10) What is the age of the oldest rocks in the Atlantic Ocean?

11) Approximately how long ago did the Atlantic Ocean begin to form?

Map of the ages of the seafloor in the Atlantic Ocean

12) Why should your answers to Questions #10 and #11 match? Revise your answers if necessary.

13) You are reading a proposal requesting money to search for evidence of a crater that caused a mass extinction on Earth 245 million years ago. The team is proposing to search a poorly explored area of the floor of the Atlantic Ocean between South America and northern Africa. Would you fund this project? Use the ages of the seafloor to support your answer.

Compare your answer of the last question to the answers of other groups.

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Figure 1. Example geology Lecture Tutorial. To download the Lecture Tutorial, please visit http://faculty.ccri.edu/kkortz/LT.shtml.

a class student-centered and interactive does not necessarily increase student learning (Hake, 1998; Libarkin and Anderson, 2005; Kirschner et al., 2006). In addition most of these techniques do not directly confront students' alternative conceptions, some cannot be used in large lecture classrooms, and some require special equipment, special classrooms, extra funds, or significant time and energy on the part of the instructor to implement.

In this paper, we describe Lecture Tutorials, our solution to some of the problems described above. We discuss them, how they were created, and how they are used in the classroom. Additionally, we show evidence that Lecture Tutorials improve introductory geology courses by increasing student learning.

LECTURE TUTORIALS

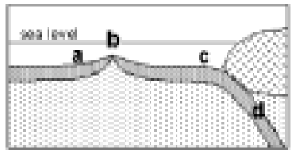
What Are They? - Our goal was to develop materials to increase learning and reduce students' retention of alternative conceptions after completing an introductory geoscience class. We recognize that most instructors will continue to use lecture as the dominant instructional approach and therefore aim to develop materials that can be readily integrated into that instructional approach.

We developed and evaluated a set of interactive exercises for geoscience classes called Lecture Tutorials. Lecture Tutorials are 10-20 minute interactive worksheets that pose questions of increasing conceptual difficulty to the students, cause conflict with alternative conceptions, and help the students construct correct scientific ideas. The students complete the Lecture Tutorials in groups during class after a brief introductory lecture on the topic.

Lecture Tutorials have been successfully developed and used in Physics and Astronomy (Shaffer and McDermott, 1992; McDermott and Shaffer, 2002; Adams et al., 2003). The Astronomy Lecture Tutorials have been tested against traditional lectures, and have been found to help students achieve significant gains in learning compared to lecture alone. For example, on conceptual understanding tests, students scored at a 50% level after lecture, but scored at a 70% level when tested after completing a Lecture Tutorial (Prather et al., 2004).

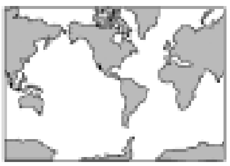
Lecture Tutorials are relatively easy to incorporate into preexisting classes without a dramatic change to the delivery of the class and without any need for special equipment, allowing all instructors to improve their classes. Prather et al. (2004) found them effective in large lecture courses, and Brogt (2007) discusses best practices for successful implementation. One drawback (common to most student-centered methods) is that they take up more time in the classroom than lecture alone, and an

CT14a. Examine the diagram to the right that shows a section of Earth's outer layers. Where would you find the <u>youngest</u> oceanic crust?



a. b. c. d.

GCI65. The map below shows the position of the Earth's continents and oceans today. The gray areas represent land, and the white represents water. Which of the following best explains why the ocean basins look the way they do?



(A) Meteor impacts caused the ocean basins to form this way
(B) Ocean basins form as continents move
(C) The ocean basins formed in cracks that were created as the whole Earth cooled after its formation
(D) The ocean basins formed in cracks that were created as the whole Earth heated after its formation

Figure 2. Example multiple choice questions used to assess the Seafloor Ages Lecture Tutorial. The first question is a Conceptest question (McConnell et al., 2006), and the second question is a Geoscience Conceptest Inventory question (Libarkin and Anderson, 2007).

instructor needs to plan this extra time into their course before implementation.

Lecture Tutorials may provide a means to effectively teach students who have a variety of learning styles. Most students learn better through social interactions when they engage the views of others (Merriam and Caffarella, 1999). When completing a Lecture Tutorial, students must interpret the information given (often in the form of diagrams and images), formulate ideas, discuss those ideas with other students, and write concise answers to a series of questions. Through this process, students use many different skills in class and have the opportunity to evaluate their own knowledge to be sure they truly understand the information they are expected to learn during the class.

A unique aspect of Lecture Tutorials is that they are designed to directly confront alternative conceptions in introductory geoscience classes. Other interactive techniques are designed to involve students in the classroom and help them learn, but these other techniques do not directly confront the students' deeply held incorrect conceptual beliefs about the Earth.

Also, Lecture Tutorials guide students to more complex ways of thinking using scaffolding questions which help support the students to answer more difficult questions. This guidance reduces the cognitive load of the students as they are trying to process new information, and it therefore helps them to more efficiently retain new knowledge than other, less guided, interactive techniques (Kirschner et al., 2006; Sweller et al., 2007).

Format - Use of Lecture Tutorials generally follow a standard format beginning with a short lecture on the relevant topic. For our example Lecture Tutorial on Seafloor Ages in Figure 1, the instructor would discuss divergent boundaries and the formation of oceanic crust.

The introductory lecture may be followed by a few conceptual multiple choice questions to determine if there has been a significant advancement of understanding by the students. These questions can be Conceptest questions (McConnell et al, 2003; McConnell et al., 2006), Geoscience Concept Inventory (GCI) questions (Libarkin and Anderson, 2005; Libarkin and Anderson, 2006), or individually written questions. This optional pretest also allows the students to identify what they do not know and what they will learn from the Lecture Tutorial worksheet.

	Class #								
	1	2	3	4	5	6	7	8	9
Igneous rock mineral sizes		o	x		o	x		x	
Sediments and sedimentary rocks		o	x	x	x	x		x	
Metamorphic rocks			x	x	x			x	
Rock Cycle			x	x	o	x		x	
Flood frequency curve	o	o			o		x	x	
Climate change and CO_2	x	o	x	x	x		x	o	
Seafloor ages		o	x	x	o	x		o	x
The outer core		o	o	x	x	x		x	
Locations of earthquakes				x	x			o	x
Earthquake intensity and magnitude	o	o	x		o		o	x	
Tsunami			x	x			o	x	
Magma source depth			x	x	o			o	
Volcanoes on other planets			x	x	x		o		

Table 1. The classes in which each Lecture Tutorial was used. X = used and tested; O = used but not tested.

Figure 2 shows examples of questions we used for the Seafloor Ages Lecture Tutorial; one a Conceptest question that directly addresses the topic and the other a Geoscience Concept Inventory question that tangentially addresses the topic. Before the Lecture Tutorial, 59% of the students answered the Geoscience Concept Inventory question correctly, and 76% of students answered the Conceptest question correctly.

The class then proceeds to work in small groups of 2 or 3 on a 10-20 minute Lecture Tutorial worksheet. The first basic, though conceptually challenging, questions are designed to introduce the students to the topic and cause conflict with their alternative conceptions. The Lecture Tutorial then guides the students by asking questions focusing on underdeveloped or misunderstood concepts and scaffolds their thinking, helping the students construct a new understanding (Hewson and Hewson, 1988; Dreyfus et al., 1990; Chan et al., 1997). The final questions on the Lecture Tutorial tend to be higher level questions, both scientifically and cognitively, that indicate whether or not the students understand the material.

In the example Lecture Tutorial (Figure 1), students begin by examining the cause and pattern of seafloor ages with a simple diagram of a divergent boundary (Figure 1, Questions 1-5). The students use that pattern to predict the ages of seafloor in the Atlantic Ocean (Figure 1, Questions 6-7), and then explain the pattern that is actually seen in the Atlantic Ocean (Figure 1, Questions

8-12). The final question (Figure 1, Question 13) asks students to apply their knowledge of seafloor ages to determine whether or not to fund a research expedition looking for evidence of a 245 million year old crater.

One unique method within Lecture Tutorials is the Student 1 vs. Student 2 debate strategy, where one hypothetical student expresses a commonly held alternative conception, and students must determine with which one they agree. An example Student 1 vs. Student 2 debate is given in Figure 1, Question 7.

While students are completing the Lecture Tutorial worksheet, the instructor circulates among the student groups and guides them if necessary. However, due to the care in the construction of Lecture Tutorials, most student groups can work through them independently without instructor assistance. In a large classroom, the instructor can also inform the students that they can ask other groups around them if they have questions. Most Lecture Tutorials also contain built-in self-checks for students, so they know if they are on the right path.

After completion, it is recommended that the instructor reviews a few of the key concepts in the Lecture Tutorial and addresses any questions the students may have before continuing with lecture. Instructors can also direct students to use their office hours for additional help or review. Although in some classes the instructor may choose to collect and grade the Lecture Tutorials, the instructor may instead explain that the students are expected to retain the concepts they learn while working on the Lecture Tutorials. The instructor can also provide the students with accurate language to describe the topic under investigation, and follow-up conceptual multiple choice questions can be used again to verify understanding.

Constructing Lecture Tutorials - Lecture Tutorials specifically target topics that are covered in most introductory classes (Kelso et al., 2000) and areas where students often have alternative conceptions (Groves and Pugh, 1996a; Groves and Pugh, 1996b; Hillman et al., 1996; Gowda et al., 1997; Kempton, 1997; Marques and Thompson, 1997; Gobert, 2000; Jeffries et al., 2001; Summers et al., 2001; Hawley, 2002; Kusnick, 2002; Vosniadou, 2002; Ford, 2003; Blake, 2004; McKenney and Webster, 2004; Ben-zi-Assarf and Orion, 2005; Dahl et al., 2005; Gobert, 2005; Libarkin and Anderson, 2005; Libarkin et al., 2005; Rebich and Gautier, 2005; Steer et al., 2005; Libarkin and Kurdziel, 2006). Having reviewed the current literature and evaluated these findings in light of our own classroom experience, we determined common topics and alternative conceptions to address in the development of the Lecture Tutorials (Table 1).

Once the topic and fundamental approach of a Lecture Tutorial is determined, the overall construction works best when the questions are reverse engineered. The first step is to construct one or two comprehensive questions for the end of the Lecture Tutorial which would indicate whether or not the students have an understanding of the topic (for example, Figure 1, Question 13). To directly address alternative conceptions we wrote Student 1 vs. Student 2 debates in which students must compare alternative conceptions to the scientifically accurate explanation (Figure 1, Question 7). In order to answer these debate questions and the comprehensive questions correctly, students should no longer have their alternative conceptions. Next, we wrote scaffolding questions to build up to the more difficult scientific concepts of the comprehensive questions and student debate questions, and included ways students could self-check their answers (Figure 1, Questions 5, 8, and 12). Within our overall approach to the topics, and particularly within the scaffolding questions, we often used figures, photographs, and diagrams as visual aids to learning. Finally, brief introductions to the Lecture Tutorials were included, giving students necessary background information. We wrote the Lecture Tutorials using language that students use, and we refrained from using geologic vocabulary as much as was possible. We wrote, and then revised, many drafts of the Lecture Tutorials before using them in the classroom for the first time.

After writing the first draft of the Lecture Tutorials but before testing their efficacy with the pre- and post-questions, we tested them in the classroom. While students were working on the questions, we moved through the classroom, answering students' questions, listening to their discussions, and overall noting where students were having difficulties. After the students completed the Lecture Tutorials, we again answered students' questions in class and noted where difficulties were. The Lecture Tutorials were then collected, and again, the questions on which students had difficulties were noted. Based on the discovered problems, the Lecture Tutorials were revised. In some cases individual questions were rewritten because students did not understand them or additional scaffolding questions were added. Some questions were omitted because they did not help students either change their alternative conception or increase their understanding. Sometimes, new alternative conceptions were discovered and new Student 1 vs. Student 2 debates were written. Most of the Lecture Tutorials went through this cycle of use in the classroom and revision by the authors a minimum of three times before being tested during this study.

DATA COLLECTION

After creating the Lecture Tutorials, we tested them in nine classes taught by three instructors at four colleges. One college is a large community college in the Northeast (Classes 1, 3, 4, and 7 in Table 1), one is a mid-sized community college in the Midwest (Class 2), one is a mid-sized community college in the West (Classes 5 and 8), and one is a large state university in the Northeast (Classes 6 and 9). The students tested for the Lecture Tutorials represent a diverse spectrum of students in terms of race, ethnicity, age, and educational background. No data were collected as an outside measure of student abilities (e.g. SAT scores). The length of the classes ranged from 50 minutes to 3 hours. Class size ranged from 16 students to 53 students, and students took these courses primarily to satisfy their general education science requirement. All the courses were Introduction to Physical Geology except Classes 1 and 7 which were Natural Hazards. The number of Lecture Tutorials given in each of the classes varied and ranged from 2 to 13 (Table 1).

Our research of the value of Lecture Tutorials was guided by several questions:

1. What is the effectiveness of Lecture Tutorials on student learning?
2. What is the effectiveness of Lecture Tutorials on student learning compared to lecture?
3. What are student attitudes towards the use of Lecture Tutorials in their introductory geoscience class?

To evaluate the success of Lecture Tutorials, we used several different methods focusing on each of our overall questions. We collected and examined many of the completed Lecture Tutorials to verify the students were correctly answering the questions, indicating they were learning. We gave multiple choice questions before and after the Lecture Tutorial. We also gave the same multiple choice questions before and after an extended lecture covering the same topics as the Lecture Tutorial in a few classes to determine if the Lecture Tutorial caused a larger change than lecture alone. We tested some of these multiple choice questions on midterm exams. Geoscience Concept Inventory (GCI) (Libarkin and Anderson, 2005; Libarkin and Anderson, 2006) scores were collected at the beginning and end of the semester. In addition, we surveyed several classes to learn about their opinions relating to the Lecture Tutorials.

Review of Lecture Tutorials - After the students completed the Lecture Tutorials, we collected a subset of them, and reviewed the student answers to verify that they were correctly answering the questions leading to learning. In some cases we reworded questions or included a self-check question when we found that students were consistently answering a question incorrectly. One instructor chose to give constructive feedback but did not assign a grade, while other instructors felt that writing feedback on the Lecture Tutorials was not necessary for several reasons. The Lecture Tutorials themselves have some built-in feedback, and we used student feedback while revising them to address specific difficulties. Also, the instructors reviewed the answers to difficult questions in class after students finished the Lecture Tutorials, allowing some time for extra questions the students might have. Finally, students asked questions while they were completing the Lecture Tutorials, and the instructor was able to give constructive feedback then.

Pre-Post Questions - After a brief introductory lecture on a topic, we gave the students several short multiple choice questions to answer. The students then completed the Lecture Tutorials and answered similar post-Lecture Tutorial multiple choice questions. Between 3 and 8 multiple choice questions were divided into 2 sets with most questions in Set A having a matching question in Set B that addressed the same point. To address sampling errors, the sets of questions were randomly distributed to the students, with approximately half the students completing Set A and the other half of the students completing Set B. After the Lecture Tutorial, the students answered the other set of questions.

The multiple choice questions were written by the authors (Kortz and Jager, 2006), taken from the Geoscience Concept Inventory (Libarkin and Anderson, 2005; Libarkin and Anderson, 2006), or taken from Conceptest questions (McConnell et al, 2003; McConnell et al., 2006). When possible, we used questions that were from other sources because we felt there would be less potential bias when the questions were written by other authors. The Geoscience Concept Inventory questions have been tested for reliability and validity (Libarkin and Anderson, 2006), and we used as many of those questions as we could; however, few directly addressed the topics of the Lecture Tutorials. Because the Geoscience Concept Inventory questions asked during the pre-post assessment did not follow the required test construction protocol (described by Libarkin and Anderson, 2007), we can not be certain that they are valid and reliable questions in this setting. Nevertheless, they are as close as we can currently get to a valid and reliable instrument in geology for measuring an increase in student knowledge. Conceptest questions have been written by other geoscience faculty based on their experiences with student knowledge and difficulties; however, they have not yet been tested for reliability and validity.

The questions written by the authors addressed the general topics that the Lecture Tutorials were designed to address. The distracters (incorrect answers) in the questions were written based on the experience of the authors, our identification of difficulties students have, and literature describing common alternative conceptions (Groves and Pugh, 1996a; Groves and Pugh, 1996b; Hillman et al., 1996; Gowda et al., 1997; Kempton, 1997; Marques and Thompson, 1997; Gobert, 2000; Jeffries et al., 2001; Summers et al., 2001; Hawley, 2002; Kusnick, 2002; Vosniadou, 2002; Ford, 2003; Blake, 2004; McKenney and Webster, 2004; Ben-zi-Assarf and Orion, 2005; Dahl et al., 2005; Gobert, 2005; Libarkin and Anderson, 2005; Libarkin et al., 2005; Rebich and Gautier, 2005; Steer et al., 2005; Libarkin and Kurdziel, 2006).

To eliminate the potential of "teaching to the test", all questions were chosen or written after the Lecture Tutorials were written. We tried to select questions from other sources (the Geoscience Concept Inventory and Conceptests) that were written for other purposes. The questions that we wrote addressed general concepts and understandings that we felt students should be able to answer after completing an introductory geoscience course.

Lecture Tutorials Versus Lecture - In order to determine whether the Lecture Tutorial was causing an increase in knowledge or if this increase was merely a result of spending more time on the topic, we used the same pre and post questions before and after an extended lecture. The format for giving the questions with the extended lecture was the same as the format for the Lecture Tutorials. A short introductory lecture was given, students answered one set of multiple choice questions randomly distributed to them on paper, an extended lecture was given (instead of the Lecture Tutorial), and students answered the other set of multiple choice questions.

The extended lecture covered the same topics that the Lecture Tutorial addressed. In fact, the Lecture Tutorial was used as an outline for the lecture, and in many of the lectures, the exact questions in the Lecture Tutorial were posed and answered by the instructor while lecturing. It was impossible to lecture on the topic of the Lecture Tutorial for the same length of time that it took for the students to fill it out. Therefore, to extend the time of the lecture to give the students an equivalent length of time on the topic, the lecture discussion sometimes went into slightly more detail than the Lecture Tutorials. This extra detail was on topics that different student groups would potentially discuss while completing the Lecture Tutorial. However, on average extended lecture still took several minutes less than it would have taken for the students to complete the Lecture Tutorial. The extended lecture did not involve any interactive techniques or active learning strategies.

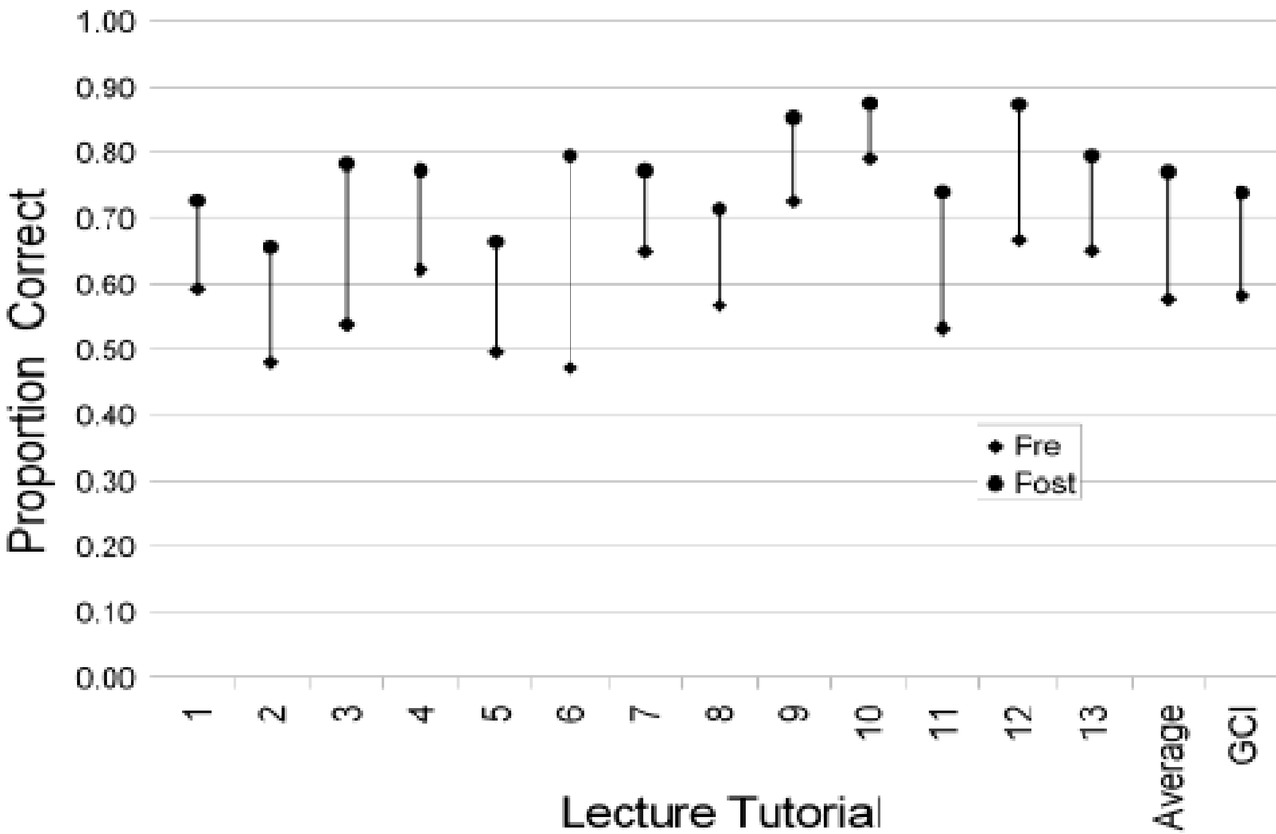


Figure 3. Pre-Post results of multiple choice questions for each Lecture Tutorial asked before the Lecture Tutorial (but after a short lecture) and after the Lecture Tutorial. 1 = Igneous Rocks and Mineral Sizes; 2 = Sediments and Sedimentary Rocks; 3 = Metamorphic Rocks; 4 = Rock Cycle; 5 = Flood Frequency Curve; 6 = Climate Change and Carbon Dioxide; 7 = Seafloor Ages; 8 = The Outer Core; 9 = Locations of Earthquakes; 10 = Earthquake Intensity and Magnitude; 11 = Tsunami; 12 = Magma Source Depth; 13 = Volcanoes on Other Planets. The GCI category refers to the 7 embedded questions gathered from the GCI.

		Pre	Post	Absolute Gain	Normalized Gain	# of Students	# of Questions	p
1	Igneous rock mineral sizes	0.59	0.73	0.13	0.33	83	480	<.003
2	Sediments and sedimentary rocks	0.48	0.65	0.18	0.34	137	6873	<.001
3	Metamorphic rocks	0.54	0.78	0.24	0.53	116	696	<.001
4	Rock cycle	0.62	0.77	0.15	0.40	94	555	<.001
5	Flood frequency curves	0.50	0.66	0.17	0.33	43	215	<.01
6	Climate change and CO_2	0.47	0.79	0.32	0.61	159	890	<.001
7	Seafloor ages	0.65	0.77	0.12	0.35	67	267	<.01
8	The outer core	0.57	0.71	0.15	0.34	121	363	<.003
9	Locations of earthquake	0.72	0.85	0.13	0.47	78	312	<.003
10	Earthquake intensity and magnitude	0.79	0.87	0.08	0.40	52	155	<.10
11	Tsunami	0.53	0.74	0.21	0.44	69	414	<.001
12	Magma source depth	0.67	0.87	0.21	0.62	42	162	<.001
13	Volcanoes on other planets	0.65	0.79	0.14	0.41	81	567	<.001
	Average	0.58	0.77	0.19	0.43	443	1973	<.001
	GCI	0.58	0.74	0.16	0.35	353	400	<.001

Table 2. Pre-Post results of multiple choice questions for each Lecture Tutorial. The scores are given as a proportion of students who answered the questions correctly. p is the probability that the gain in scores is a result of chance. Normalized gain is (Post - Pre) / (1 - Pre). The GCI row refers to the seven embedded questions gathered from the GCI.

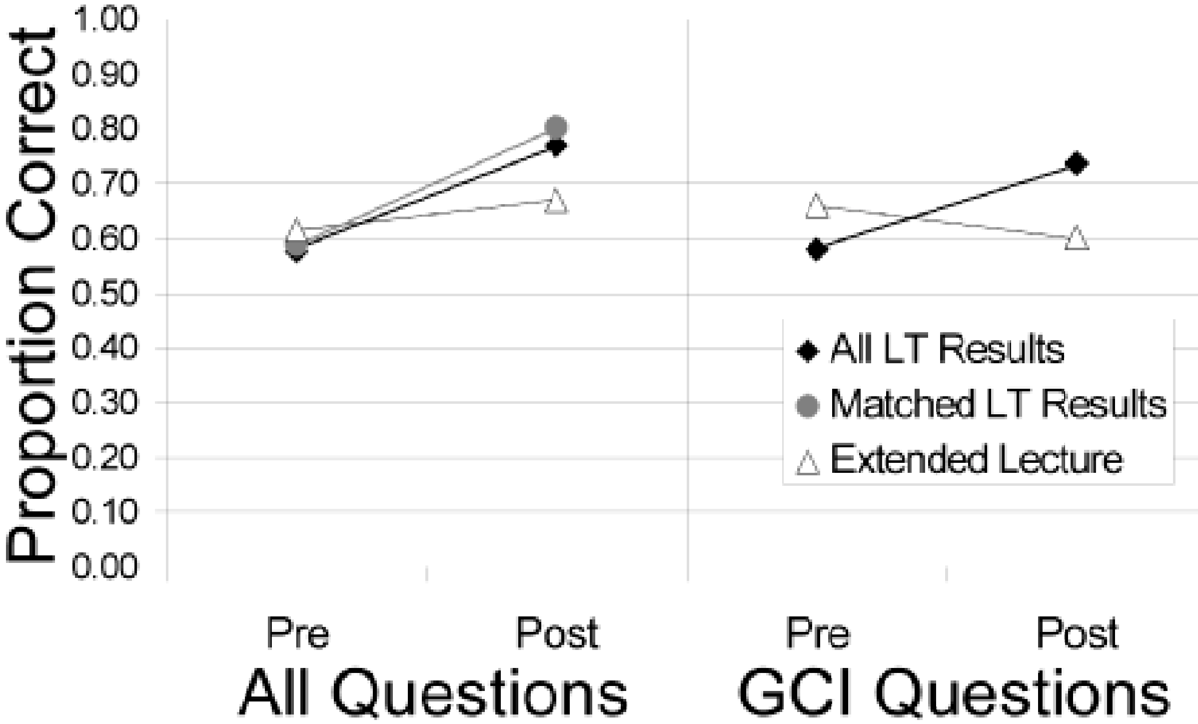


Figure 4. Pre-Post results for Lecture Tutorials compared to extended lectures. The matched Lecture Tutorial results are for classes that were similar to the classes used for the extended lectures (same instructor at the same school). Two of the five GCI questions were not used in the matched Lecture Tutorial results, so the matched Lecture Tutorial results for the embedded GCI questions are not shown.

Some of the multiple choice questions used for the pre- and post-evaluation of the Lecture Tutorials were asked again on midterm exams. Because the students did not get their pre- and post-multiple choice questions back and were not told the correct answers, we feel that using the same questions on the Lecture Tutorial evaluation as on the exams did not influence student performance on the exam. We compared the scores on questions on exams relating to the Lecture Tutorials of students who completed the Lecture Tutorials to the scores on questions on exams of students who did not complete the Lecture Tutorial.

Geologic Concept Inventory (GCI) - In classes where a large number of Lecture Tutorials were used, a 15-question Geoscience Concept Inventory quiz was given at the beginning and end of the semester (constructed as explained by Libarkin and Anderson, 2007). The questions on this quiz were not the same questions used in the pre- and post-evaluation of the Lecture Tutorials.

Student Surveys - Student evaluation surveys were given at the end of the semester in several courses taught by one of the authors (KMK) that used the Lecture Tutorials and other worksheets. A couple of the questions on the survey asked about the Lecture Tutorials, and the answers to these questions were analyzed. These questions were asked to learn student opinions of the use of Lecture Tutorials in their class.

RESULTS

Pre-Post Questions - Figure 3 and Table 2 show the pre and post scores on the multiple choice questions for each Lecture Tutorial. On average, student scores increased from 58% correct to 77% correct after the Lecture Tutorial (19% gain) (number of questions = 5759; probability the gain was a result of chance < .001 using a t-test). The Lecture Tutorial with the largest increase in scores is Climate Change and Carbon Dioxide, which increased from 47% to 79% correct, a gain of 32% ($n = 890$; $p < .001$). The smallest increase in scores is Earthquake Intensity and Magnitude, which increased from 79% to 87%, not a statistically significant gain because $p > 0.05$.

Embedded in the multiple choice questions were 7 questions from the GCI. For these questions, the percentage of questions answered correctly increased from 58% to 74%, a gain of 16% ($n = 400$; $p < .001$). Because these GCI questions were not bundled together as a subtest described by Libarkin and Anderson (2007), these results cannot be compared to GCI subtest results.

Lecture Tutorials Versus Extended Lecture - Figure 4 compares the results for the pre- and post-questions used for Lecture Tutorials and extended lectures. We compared the results of students listening to the extended lectures to the results of all students who completed Lecture Tutorials. In addition we compared the results of the extended lectures to a subset of similar classes who completed the Lecture Tutorials. These matched classes were similar to the classes used for the

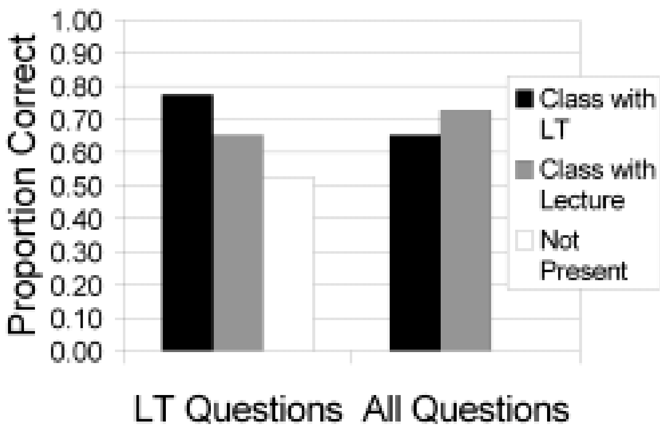


Figure 5. Scores on questions on exams assessing the Lecture Tutorials comparing the class that did the Lecture Tutorial with the class that heard extended lectures. The exam scores for the students that were not present for either the Lecture Tutorial or the extended lecture on that topic are also included.

extended lecture in that they were taught by the same instructor at the same school covering the same material. The matched Lecture Tutorial results are similar to the results when using all the students who completed the Lecture Tutorial.

The extended lecture did not increase the students' knowledge as much as the Lecture Tutorials. We tested the extended lecture in 7 different situations (using 2 different instructors, 5 different classes, and 5 different Lecture Tutorials). For the extended lecture, the students' scores increased from 62% to 67% (a 5% gain) (n = 869; $p > .05$, which is not significant because there is a greater than 5% probability that the gain is a result of chance), compared to a 22% gain in the matched courses (n = 693; $p < .001$) and a 20% gain for all students who completed those Lecture Tutorials (n = 2146; $p < .001$). Furthermore, when the results for the 5 embedded Geoscience Concept Inventory questions are analyzed, student scores actually slightly decreased after the extended lecture, from 66% correct before to 60% correct, but this is not a statistically significant change (n = 146; $p > .05$). This is unlike the 19% increase on the same 5 embedded Geoscience Concept Inventory questions for all students who completed the Lecture Tutorial (n = 240; $p < .003$).

In addition to the extended lecture, we tested relative effectiveness of Lecture Tutorials compared to lectures by using some of the pre-post multiple choice questions on exams for two classes (Class 7 and another Natural Hazards course) taught by the same instructor during the same semester. The classes were taught identically, except one course used five Lecture Tutorials and the other course used lecture alone to cover those same topics (Figure 5). Achievement differences are apparent upon examining the seven multiple choice exam questions (of 50 overall) that were used to assess the Lecture Tutorials. For these questions, the class that completed the Lecture Tutorials scored 12% higher than the class that learned those topics through lecture ($p < .03$). The Lecture Tutorial class did not show the same increased score on the other exam questions not relating to the Lecture Tutorials, although these exam questions have not been tested for validity or reliability.

One of the assessment questions for the Climate Change and Carbon Dioxide Lecture Tutorial was used on exams in three different classes taught by the same instructor. In Courses 3 and 4 in the study, slightly more than one 50-minute class was devoted to climate change, the Lecture Tutorial was used, and 81% of the students (n = 43) answered the question correctly on the exam. Although the students did see the exam question previously during the pre- or post-testing, we feel it did not influence the student exam scores because the students were not told the answer to the question during the pre- and post-testing, they did not write the question in their notes, and there were several weeks between the Lecture Tutorial and the exam. In a different course taught by the same instructor, three 50-minute classes were devoted to climate change, but the Lecture Tutorial was not used. One of those 50-minute classes was primarily lecture about climate change and its consequences, one class consisted of a large group discussion of differing predictions of consequences of climate change, and Al Gore's An Inconvenient Truth was shown in the third class. On the exam in this non-Lecture-Tutorial class, only 21% of the students (n = 29) answered the same question correctly. Although much more time in class was devoted to climate change and its consequences, and methods other than lecture were used for the non-Lecture-Tutorial class, students who completed the Lecture Tutorial performed significantly better ($p < .001$) on the question dealing with climate change on the exam.

Geoscience Concept Inventory (GCI) - Geoscience Concept Inventory scores were obtained at the beginning and end of the semester for three courses that included more than ten Lecture Tutorials. This GCI subtest is a valid and reliable measure because it followed the protocols of Libarkin and Anderson (2007) for constructing valid and reliable subtests. In these courses, the GCI score increased on average from a pre-score of 39.3 +/- 13 (n = 86) to a post-score of 48.0 +/- 14 (n = 64). The absolute gain in score is higher ($p < .02$) than the average given in Libarkin and Anderson (2005), where the pre-course scores were 41.5 +/- 12, and the post-course scores were 45.8 +/- 13 (Libarkin and Anderson, 2005). However, because there are so many variables that influence student learning in the classroom and because the 15-question GCI did not test the same concepts that were addressed in the Lecture Tutorials, we cannot attribute the rise in GCI scores solely to the Lecture Tutorials themselves. The Lecture Tutorials did contribute to increased student learning in the classroom, though, and this increase could very likely "spill over" into other topics that the Lecture Tutorials did not address, but the GCI tested.

Student Surveys - At the end of the semester, evaluations were given to students in classes taught by one of the instructors. Students responded to the question "The in-class exercises helped with my understanding of the subject" on a Likert scale, with 6 = strongly agree, 5 = agree, through 1 = strongly disagree. Ninety-nine percent of students (n = 209) agreed with the statement. In all of these classes, worksheets in addition to the Lecture Tutorials were also used, so the student response pertains to both the worksheets and the Lecture Tutorials. The worksheets are similar to the Lecture Tutorials, but they are usually less formal and shorter. In Classes 3 and 4 in the study, a larger number (10 or 11) of Lecture Tutorials were used as well as other worksheets. In these classes, 100% of students (n = 40) agreed with the statement, and the average Likert scale response was 5.6 (between agree and strongly agree).

On the same survey, students were asked the open answer questions "Do you think the in-class exercises were a useful part of class?" Typical student responses were:

> Yes, because it applied what we've just learned.
>
> Yes because you had to think, not just listen.
>
> Very much so. This is where I put everything together, and where it all made perfect sense to me. I might have not understood completely everything at first, but as I did the work it became clearer to me.
>
> Yes, it was a completely new way of getting me to learn a topic through lecture then practicing what I just learned. The material that I had trouble with stood out immediately and gave me a chance right then to ask questions. Overall helped me to do great on tests.

There were no negative comments that pertained to the Lecture Tutorials on this survey. Because the student written response agreed with the student response on the Likert-scale question in all cases except one, we view these results as valid and reliable.

DISCUSSION

We wrote Lecture Tutorial worksheets to resolve the conflict of how students learn and how instructors are teaching. Many students are leaving introductory geoscience courses with their alternative conceptions still intact, which means they are not always learning what we hope they learn. Lecture Tutorials specifically combat this lack of learning by adding interactivity to the classroom and engaging the students to think about their alternative conceptions while allowing faculty to use lecture as their primary method of instruction. Lecture Tutorials are relatively easy for instructors to implement in their courses, supplementing lecture. Therefore, most instructors can include the Lecture Tutorials without the need for significant faculty professional development or a dramatic time investment.

Students showed a significant increase on test questions after completing most Lecture Tutorials. Embedded in these questions were the Geoscience Concept Inventory questions, on which students showed a similar increase in knowledge.

Not all Lecture Tutorials work equally well, when comparing the pre- and post-multiple choice scores. Specifically, the Earthquake Intensity and Magnitude Lecture Tutorial did not result in a statistically significant increase in student knowledge. This Lecture Tutorial was written based on an alternative conception seen in one of the author's classrooms. However, this alternative conception may not apply to the general population. As a result lecture and the Lecture Tutorial perform equally well for improving student learning on this topic.

For the Seafloor Ages Lecture Tutorial (Figure 1), student scores in one class decreased dramatically after completing the Lecture Tutorial (from 74% correct to 45% correct). Upon examination of students' post-Lecture Tutorial answers, we discovered that many of them correctly answered the pre-question, but then used that same answer for the post-question with the same diagram, even though that answer was incorrect. Therefore, we think that the lack of a significant increase in question score may be due to the students not reading the questions fully. As a result, the student scores on this Lecture Tutorial for this class are not included in the final results.

Student scores for different classes taught by different instructors were also compared to get a range of the effectiveness of Lecture Tutorials in the classroom. We compared only those classes in which at least five Lecture Tutorials were given and tested. The improvement in student scores after the Lecture Tutorials ranged from 10% (Class 5) to 22% (Class 6), and the increase was statistically significant for all classes.

Although student performance in some classes on certain Lecture Tutorials were not as large as in other classes, this does not mean that the Lecture Tutorials are not worth doing. Students still receive the benefits of peer discussion and student-focused learning from completing the Lecture Tutorials. Nevertheless, they may be able to learn this information through lecture alone. Other Lecture Tutorials, where the increase is especially large (e.g. Climate Change and Carbon Dioxide and Magma Source Depth), appear to be confronting more deeply held alternative conceptions that lecture alone does not effectively change for all students.

For most Lecture Tutorial topics, students answered more questions correctly after completing the Lecture Tutorial compared to extended lecture on the same topic. This lack of change for lecture alone suggests that additional time-on-topic does not drive the increase in knowledge. Instead, the Lecture Tutorial methodology engages the students and changes the way they think about difficult topics.

The effectiveness of the Lecture Tutorials is not a matter of the Lecture Tutorials closely matching the assessment test. The extended lectures closely followed the topics of the Lecture Tutorials and in some cases used the same language as the Lecture Tutorial, except in lecture form. If the increase in scores after the Lecture Tutorial was a result of the questions closely matching the Lecture Tutorial, then the same increase would be expected after the extended lecture on the same topic. This lack of increase indicates that the students are learning more from the Lecture Tutorials than just how to answer the multiple choice questions. In addition, the multiple choice questions were chosen after the Lecture Tutorials were written and from other sources, when possible, to avoid the possibility of question bias.

The increase of scores on the pre- and post-Lecture Tutorial assessment questions asked on exams indicates that the increase in student knowledge as a result of the Lecture Tutorial is not a temporary, short-term increase. The exams were given weeks after the Lecture Tutorials, yet students who completed the Lecture Tutorials still retained more knowledge and performed better on the exam questions. Although students could use the Lecture Tutorials to study, they could also use their notes and books to study. Again, this suggests that Lecture Tutorials fundamentally changed students' understanding of topics.

Student surveys overwhelmingly indicate that they felt the Lecture Tutorials helped them learn the topic and were a useful part of the class. They liked that the Lecture Tutorials made them apply what they learned in lecture and think about the topic. If they did not understand the material, it became clearer to them when they worked on the Lecture Tutorial in class.

Thirteen Lecture Tutorials have been developed and tested, and we are creating additional ones to cover a wider range of topics in introductory geology. We would like to test Lecture Tutorials in a wider range of schools. It is our goal to disseminate the Lecture Tutorials and make them available to all instructors who wish to use them. In order to maximize the distribution of Lecture Tutorials and simplify their use in the classroom, we are currently in discussion with a publisher to publish the Lecture Tutorials as a workbook. To obtain copies of Lecture Tutorials, please contact the first author, or visit the webpage: http://faculty.ccri.edu/kkortz/LT.shtml for a few example Lecture Tutorials.

CONCLUSION

Lecture Tutorials were written to increase student learning in the introductory undergraduate geoscience classroom by engaging the students and guiding them through small conceptual steps to a more scientific way of thinking. Our results demonstrate that students learn and retain significantly more from the Lecture Tutorials than they do through lecture alone. Although brief, the Lecture Tutorials create a learner-centered environment that may promote significant gains in conceptual understanding. In addition, students enjoy using the Lecture Tutorials in the classroom and feel that the Lecture Tutorials aid their learning.

The Lecture Tutorials are relatively short, straightforward, and focused on common topics, which allows instructors to include the Lecture Tutorials in a course without a dramatic redesign. This may be particularly important in large introductory geoscience courses in which other interactive learning approaches are used with difficulty.

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