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A Case-based Curriculum for Introductory Geology

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ABSTRACT

For the past 5 years I have been teaching my introductory geology class using a case-based method that promotes student engagement and inquiry. This article presents an explanation of how a case-based curriculum differs from a more traditional approach to the material. It also presents a statistical analysis of several years' worth of student assessment data from both the traditional and case-based curricula. These analyses demonstrate that the case-based method not only improves student learning relative to a traditional curriculum, it also improves students' ability to apply higher-order thinking skills to the study of the earth. © *2011 National Association of Geoscience Teachers*. [DOI: 10.5408/1.3604824]

INTRODUCTION

The recent emphasis on assessment in higher education has given educators the tools necessary to test the effectiveness of a wide variety of pedagogical methods and styles. Geology and geoscience education have kept pace with this trend, as even a cursory glance through any issue of the *Journal of Geoscience Education* will illustrate. While numerous geoscience educators have continuously refined classroom techniques, constructivist demonstrations, and lecture supplements to more effectively deliver their curriculum, fewer have evaluated that curriculum as a whole.

Since the plate tectonic revolution of the 1960s, a stereotypical curriculum for teaching introductory geology has emerged and become entrenched. That curriculum is effective for teaching students the basic factual information of our science, but it is suboptimal when it comes to teaching the scientific method and higher-order thinking skills. For the past 5 years, I have been teaching my own introductory geology classes using a case-based approach to the material. This approach has become common in the teaching of many other fields and several previous studies have demonstrated its effectiveness in these fields for improving student engagement and learning (e.g., Barnes *et al.*, 1986; Lawson *et al.*, 1990; Hake, 1998).

In the case of my introductory geology classes, assessment data reveals that a case-based approach to teaching does more than improve student engagement and learning: It also improves students' ability to engage in higher-order thinking about the subject matter. Beyond improving student understanding, this teaching method has additional benefits. The case-based approach more closely models the scientific method as used in geology than does a traditional curriculum, in that it infers broad principles inductively from field data. It also taps into the curiosity about geology that brings many college freshmen into our classrooms in the first place.

THE TRADITIONAL APPROACH TO INTRODUCTORY GEOLOGY AND THE CASE FOR CASES

It might seem obvious to say that introductory geology classes share a common curriculum. After all, introductory geology classes are presumably all trying to teach students the same information. By *curriculum*, however, I mean not only the subjects that are covered in a class, but also the order in which those subjects are covered. For example, most introductory geology classes will include segments on both volcanoes and weathering, but there is no particular pedagogical reason why those topics should be taught in the same order in those classes.

It would be exceedingly difficult to collect comprehensive data on the curricula of all introductory geology classes currently being taught at colleges and universities around the United States. Textbook tables of contents, however, provide a reasonable proxy. Table I shows the results of a series of pair-wise Spearman rank order correlations that I performed on the tables of contents of five of the most popular textbooks being sold today (based on their Amazon.com rankings). With 99.9% significance, there is no difference in the order of the contents in these books. Assuming that the classes that use these books primarily follow the order of their contents, then it is logical to assume that those classes all share a common curriculum.

To demonstrate how well ingrained this common curriculum has become, I reran the rank order correlation including a sixth book, the third edition of Gilluly *et al.* (1968) *Principles of Geology*. Here the correlation was weaker ($r = 0.607$), but its curriculum was still significantly correlated with the rest of the textbooks ($p < 0.01$). The reason that this correlation is particularly remarkable is that this sixth textbook was published in 1968, only a few years after the plate tectonic revolution. The curriculum common to these books is not only ubiquitous; it is also old enough to be described accurately as traditional.

A curriculum does not become this remarkably common without having some significant strengths and merits. It has helped to train almost every professional geologist working today, providing us with the generalizable knowledge necessary to explore and understand the earth. The question remains, however, as to whether some alternative methodology might be more effective in teaching

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TABLE I: Results of a Spearman rank order correlation analysis of the tables of contents of some popular introductory geology textbooks. All correlation coefficients are significant at $p < 0.001$ indicating that there is no statistically significant variation in the order in which these books cover geological concepts.

	SPP&F	C&W	PC&M	TL&T	MW&H
SPP&F	X				
C&W	r = 0.950	X			
PC&M	r = 0.846	r = 0.802	X		
TL&T	r = 0.994	r = 0.963	r = 0.789	X	
MW&H	r = 0.990	r = 0.963	r = 0.779	r = 0.989	X

Key:
SPP&F: Skinner *et al*., 2006, 5th edition
C&W: Chernicoff and Whitney, 2006, 4th edition
PC&M: Plummer *et al*., 2007, 12th edition
TL&T: Tarbuck *et al*., 2004, 8th edition
MW&H: Monroe *et al*., 2006, 6th edition

geological concepts, or in teaching the thinking skills that underlie geology as a science. One possible alternative is case-based teaching.

Case-based education turns the traditional approach to pedagogy on its head. A traditional curriculum in any discipline begins by teaching students broad concepts and fundamentals and then applying those principles to selected examples. Case-based education begins with those selected examples and requires the students to work constructively, using information from the examples to infer what the principles at work must be (Savery and Duffy, 1996).

Case-based education is already part of the curriculum at many business and law schools (Barnes *et al*., 1986) and has, over the past few decades, become a useful tool for biology and physics instruction as well (Lewis, 1994). In fact, case-based teaching has become so common in some fields that entire taxonomies exist for different types of cases depending on the length of the case, the role of the instructor, and the number of students involved (Hake, 1998; Herreid, 2006). Research into student learning in case-based science courses has shown that students in case-based courses are typically more engaged, think more critically about scientific questions, and become more comfortable applying scientific principles (Herreid, 1994).

Case-based education has an additional strength that is particularly relevant to geology, in that it capitalizes on the curiosity that brings students into our classrooms in the first place. Part of the impetus for my course redesign was a frustration I often felt in talking to students on the first day of class. Almost inevitably, each semester students would stay behind that first day and ask me about some geologic feature of Southern Utah or Yellowstone National Park that they had seen. Equally inevitably, the students would seem crestfallen when I told them that we would get to those things after the midterm, but that in order to really understand them we first needed to talk about fluid flows and mineral formation. Under a case-based curriculum, the same subjects and sites that foster student curiosity and that bring students into a geology classroom in the first place also drive their learning.

IMPLEMENTATION

In designing this new curriculum, I had two goals in mind. I wanted to create a greater sense of narrative engagement in my class. In other words, I wanted my students to get interested in the story of how the earth works, and how it has changed through time. Moreover, I wanted this increased engagement to get my students curious about the earth and how geologists learn about it. This combination of narrative engagement and curiosity should be reflected in an improved ability to interpret data and understand geologic processes.

Doing something new and interesting in the classroom is usually fun and refreshing for the instructor, but change is only worthwhile if it improves students learning. When I decided to change my introductory geology class to a case-based class, I wanted to make sure that it would be worthwhile. As such, implementing the change in curriculum actually required three discrete steps.

The first step in changing my curriculum took place in the fall of 2004. During this semester, I taught introductory geology one last time using a traditional curriculum. I did this in order to collect data on exactly how well my students were learning concepts under this curriculum. Each day's class began with a short (2–3 question) multiple-choice quiz on the previous day's material. Additionally, each hour exam incorporated 20 multiple-choice questions as well as a few short answer or problem-type questions. These evaluations provided me with over 100 different points of assessment data apiece for the 50 students who took the class that semester.

The second step in changing my curriculum was creating the curriculum itself. I spent the summer of 2005 restructuring the class and finding case studies. I wanted these case studies to be both geologically and geographically diverse. I also tried to choose areas that had some particularly puzzling aspect to their geology. This change in curriculum was inspired in part by students asking questions about things they had seen prior to coming to class. I wanted that sense of curiosity to continue through the semester and drive students' learning.

The final step in changing my curriculum was assessing the effectiveness of the new curriculum. I began using the case-based method in the fall of 2005. While the curriculum was quite different from what I had done in the past, I continued to evaluate student learning in the same fashion. Every session began with a multiple-choice quiz and each exam incorporated multiple-choice questions as well. Since this was still an introductory geology class, I was able to keep the topics of the questions, though not the questions themselves, similar from semester to semester. I therefore could compare students' performance on these quizzes and exams under the case-based curriculum with students' performance under the traditional curriculum.

THE CASE-BASED CURRICULUM

Table II shows the topics that I covered in class and the order in which I covered them when I still taught introductory geology using a traditional curriculum. When I redesigned my class around a case-based model, I wanted to be sure that the conceptual base for the class remained the same; that is, that students would leave the class with the same knowledge base that they would gain through a

TABLE II: The order of lecture material I used when teaching introductory geology with a traditional curriculum.

- Part One: The Age and Structure of the Earth
    - Deep Time
    - Sedimentary Rocks
    - Relative Dating
    - Igneous Rocks
    - Metamorphic Rocks
    - Radiometric Dating
    - Rock Deformation
- Part Two: Plate Tectonics
    - Mountain Formation
    - Seafloor Spreading
    - Plate Tectonics
    - Relative Plate Motion
    - Absolute Plate Motion
    - Plate Boundary Types
    - Earthquakes
- Part Three: Surficial Processes
    - Global Climate Change
    - Stable Isotope Geochemistry
    - Glaciers and Glaciation
    - Weathering and Erosion
    - Hydrologic Cycling

TABLE III: An outline of the case-based curriculum that I have been using for the past several years. Note that all of the same topics are still covered but they are covered in a different order and using an inquiry-based format that creates a narrative context for the information.

- Part One: The Great Salt Lake
    - Question: Why is it so salty?
        - Deep Time
        - Relative Dating
        - Hydrologic Cycling
        - Minerals
        - Weathering & Erosion
        - Clastic Sedimentary Rocks
        - Metamorphic Rocks
        - Intrusive Igneous Rocks
    - Answer: Salt in the Great Salt Lake comes from the weathering and erosion of igneous intrusions in the nearby Wasatch Mountains. The terminal nature of the lake allows trace amounts of sodium and chlorine to accumulate and concentrate over time.
- Part Two: Tibet and Iceland
    - Question: Where is the world's tallest mountain?
        - Isostasy and Isostatic Rebound
        - Earthquakes
        - The Deep Structure of the Earth
        - Volcanic Igneous Rocks
        - Paleomagnetism
        - Absolute Dating
        - Rock Deformation
        - Seafloor Spreading
        - Mountains and Mountain Formation
    - Answer: Iceland claims to have the tallest mountain on earth (Oraefajokull) because they start measuring from its base at the seafloor. If you were to measure Mt. Everest from its true base deep in the mantle, however, it would still dwarf any other mountain on earth.
- Part Three: The Pacific Ocean
    - Question: Why are the volcanoes in the middle of the ocean so different from the ones around the edge?
        - Plate Tectonics
        - Absolute Plate Motion
        - Relative Plate Motion
        - Convergent Plate Boundaries
    - Answer: The volcanoes in the middle of the Pacific are different than the ones around the edge because they are shield volcanoes, not stratovolcanoes.
- Part Four: Eastern Africa
    - Question: How has Lake Tanganyika persisted for so long?
        - Divergent Plate Boundaries
        - Triple Junctions
        - Euler Poles
    - Answer: Lake Tanganyika continues to get deeper through time because it is on a divergent boundary between the Nubian and Somali Plates.

traditional curriculum. Under a case-based curriculum, however, the organizing features of the semester are not principles of geology, but notable geologic locales.

My case-based introductory geology class is organized around six geologic questions. Each of these questions is in turn related to a particular region of the earth. In studying these regions, students learn the geologic principles necessary to answer the questions. The questions are:

- The Great Salt Lake: Why is it so salty?
- Tibet or Iceland: Where is the world's tallest mountain?
- The Pacific Ocean: Why are the volcanoes in the middle of the ocean so different from the ones around the edge?
- Eastern Africa: How has Lake Tanganyika persisted for so long?
- The Caribbean: How do tectonic processes affect global climatic patterns?
- Antarctica: Will there be a geologic record of human activity?

Table III shows the order in which students learn geologic principles under this curriculum. Rank order analysis shows no significant correlation between the structuring of this curriculum and the more traditional curriculum described previously ($r = 0.393$).

Considering how different this curriculum is from that presented in most textbooks, finding the right supplemental material for the class was a challenge. In previous years, I had assigned Chernicoff and Whitney's (2006) textbook *Geology* and made my lecture notes available on-line. Under the new curriculum, I changed the status of the textbook from *required* to *suggested supplement*. There were no formal assignments from the book, but I put a copy on reserve in the library and suggested that it might be a good place for students to look up concepts that they might have additional questions about after class. In place of the

TABLE III. *Continued*

- Part Five: The Caribbean
    - Question: How do tectonic processes affect global climatic patterns?
        - Chemical Sedimentary Rocks
        - Oceanic and Atmospheric Circulation
        - Stable Isotope Geochemistry
        - Transvergent Plate Boundaries
    - Answer: The motion of continental plates can change patterns of oceanic circulation, and therefore climatic patterns.
- Part Six: Antarctica
    - Question: Will there be a geologic record of human activity?
        - Milankovich Cycling
        - Glaciers and Glaciation
        - Atmospheric Chemistry
        - Global Warming
    - Answer: Human activity has already changed global climatic patterns and atmospheric chemistry significantly enough to be recorded in the geologic record.

textbook, I required students to purchase the USGS map *This Dynamic Planet* (Simkin *et al*., 2006). The map is a map of the earth including plate boundaries and undersea topography. Additionally, the map shows the location of all recorded volcanic eruptions over recorded history as well as the location, intensity, and depth of all significant earthquakes of the past several centuries. I also continued to make my lecture notes available on-line.

In designing this new curriculum, my goal was not only to increase student engagement with the subject matter but also to make the students' class experience more accurately reflective of how the science of geology is done. The principles that underlie modern geology were, for the most part, inferred from fieldwork. Likewise, in a case-based course, the principles of geology are inferred by studying real geological locales.

Assessing the Curriculum: Data

In order to analyze changes in student performance across the two curricula, I relied primarily on data obtained from multiple-choice questions. Multiple-choice questions are an effective way to quickly capture students' understanding of geological concepts. Furthermore, carefully designed multiple-choice questions can also test students' ability to apply these concepts and to use their knowledge toward other higher order thinking skills (Fuhrman, 1996).

I devised five different types of multiple-choice questions, reflecting five different stages of learning and thinking as described by Bloom (1956):

- Questions that required simple factual recall.
- Questions that required students to define a term.
- Questions that required students to interpret data.
- Questions that required students to extrapolate the results of a process.
- Questions that required students to classify objects.

Of these five question-types, I coded factual recall and definition questions as testing lower-order thinking skills. I coded interpretation, classification, and process-related questions as testing higher-order thinking skills. Examples of each type of question are as follows.

Factual Recall
The currently accepted age of the earth is:

a. 4,500,000,000 years
b. 30,000,000 years
c. 5,400,000,000,000 years
d. 220,000 years

Definition
The large pebbles that move along the bottom of a stream are called the stream's:

a. Bed load
b. Suspended load
c. Wide load
d. Cobble load

Interpretation
Sediments that accumulate in stagnant swamps and bogs are sometimes very fine-grained and dark black in color. These are also characteristics of sediments that accumulate in which of the following environments?

a. The deep ocean
b. Streams
c. Beaches
d. Lakes

Processes
After two half-lives, what percentage of a radioactive isotope will have decayed into a daughter product?

a. 100%
b. 75%
c. 50%
d. 25%

Classification
Basalt is an extrusive igneous rock with a chemical composition most similar to:

a. Granite
b. Andesite
c. Sandstone
d. Gabbro

For every multiple-choice question on every quiz and every exam, I recorded the percentage of students that got that question correct as well as the type of thinking being tested. I continued using multiple-choice questions after making the change to case-based education. In some cases, I would use a different question to test the same topic; in other cases I would use the same question from semester to semester with different incorrect answers for the students to choose from.

Beginning in the fall of 2009, I added a second source of data to my analysis of student performance. On the first day of class, I gave my students a 15-question quiz made up of questions from the Geoscience Concept Inventory (GCI) (Ward *et al*., 2010). I did not figure this quiz into their average for the semester, and in fact, did not return it to them at all. Instead, those same 15 questions, in a different order, reappeared on the final exam. I then used a comparison of their pre- and post-test scores as a measure of individual student learning over the semester. Since the GCI website contains results of similar evaluations from across the country, this data allowed me to compare my students' learning to that of students at other institutions. The GCI data also provided a way of checking the validity of my own multiple-choice results. The Geoscience Concept Inventory has been thoroughly vetted and has gone through multiple iterations of fine-tuning in order to ensure that the questions contain no discernable gender or ethnic bias (Ward *et al.*, 2010).

Assessing the Curriculum: Analysis

In order to assess whether and how student understanding of the material changed along with the changing curriculum, I performed three different types of analysis. The first of these was a very broad-scale comparison of all of the responses my students gave to quiz and exam questions in the last year that I used the traditional curriculum versus the subsequent years of using the case-based curriculum.

For the purposes of this study, when I collected my multiple-choice data, I collected it at the question level, in order to maintain student privacy. In other words, for each question, I have a record of the percentage of the students in each year's class that got that question correct. I used a Student's T-test (Sokal and Rohlf, 1995) to determine whether there was a significant difference in student performance across the two curricula. I used a standard, rather than pairwise T-test, because the questions were not identical from year to year, but rather tested identical concepts.

In addition to looking for large-scale changes in student understanding across curricula, I also looked more narrowly within question types. I broke out each of the five different types of questions and ran separate T-tests on each of these in order to look for statistically significant changes in student performance on questions that required different ways of thinking.

For my 2009 data, I also performed two different types of analyses using students' performance on the GCI-based pre-test and post-test for the semester. This data gave me the opportunity to see how students' understanding of basic concepts changed over the course of the semester. Previous studies using the GCI to compare pre-test and post-test scores have incorporated pairwise T-tests with linear regression (Libarkin and Anderson, 2005) and have found that, nationwide, post-test scores are very highly correlated with pre-test scores. This is a depressing result, implying that, for the most part, students leave introductory geology classes with little more than the information with which they entered.

Hake (1998) proposed an interesting alternative to simple change scores that eliminates the problem of high correlation between pre-test and post-test scores. Percent gain ($\%g$) is a measure of students' improvement from pre-test to post-test relative to their maximum possible improvement. Mathematically it is expressed as

$$\langle \%g \rangle = \frac{S_f - S_i}{S_{\max} - S_i}$$

where S_i is student's initial (pre-test) score, S_f is a student's final (post-test) score, and $S_{\max}$ is the maximum possible score that a student could score on the pre-test —in this case, 100%. Studies of over 6500 students across 62 different introductory college physics classes, have shown that $\%g$ is a reliable metric of student improvement, with no demonstrable correlation to the prior knowledge reflected in their pre-test scores (Hake, 1998). In addition to the T-tests, I also calculated $\%g$ scores for my students and for the class as a whole.

Assessing the Curriculum: Results

Student's T-tests comparing how students performed on multiple-choice questions under a case-based versus traditional curriculum showed a statistically significant difference between the two populations. On average, 75% of students learning under a traditional curriculum got each question right, as opposed to 78% of students learning under a case-based curriculum. While this difference may seem small, the large sample size of questions and students leads to its significance ($p < 0.05$).

The results of this analysis become more interesting when student performance is broken down by question type. Table IV shows the percentage of students getting each different type of question correct under the traditional and case-based curricula. The entire shift in student learning from one curriculum to the next is being driven by improvement in answering questions that test classification, interpretation, and understanding of process. Each of these three question types shows significant ($p < 0.05$) improvement under the case-based curriculum. Students' ability to recall factual information also appears to increase under the case-based curriculum, although this increase is not statistically significant. Interestingly, the students' ability to define terms drops slightly, but significantly, under the case-based curriculum ($p < 0.05$).

Finally, comparing pre-test and post-test results from the GCI-based quiz that I gave to students in 2009 also shows that significant learning had occurred under the case-based curriculum. Of the 46 students who took both the pre-test and the post-test, all 46 scored better on the post-test. Students' mean score on the pre-test was 7.35 questions correct out of 15, almost identical to the national average of between 7.2 and 7.3 (Libarkin and Anderson, 2005). On the post-test, the students' mean score was 11.67 questions correct. A pairwise Students' T-Test shows that this result is significant with a p-value far less than 0.001.

While the T-tests and change scores are effective metrics demonstrating that my students learn under this new curriculum, percent gain scores show how much they have learned. Percent gain scores for the students in the 2009 class ranged from 0.25 to 1.00, with a mean and median of 0.67 and a mode of 0.8. Previous studies in physics research have delineated a $\%g$ score of 0.3 as the division between low and medium levels of learning and 0.7 as the division between medium learning and high learning (Hake, 1998). Of the 47 students who took my introductory geology class using a case-based method, 20 (43%) achieved a high level of learning, 26 (55%) achieved a medium level of learning, and only 1 (2%) achieved a low level of learning.

TABLE IV: Percentage of students answering quiz and exam questions correctly under a traditional and a case-based curriculum. Students learning under a case-based curriculum have a statistically significant ($p < 0.05$) improvement in overall performance and in their ability to apply higher order thinking skills to the study of the earth. There is a statistically significant decrease in students abilities to define terms, but when taken as a whole, lower order thinking skills show no significant change across curricula.

Question type	Traditional curriculum (%)	Case-based curriculum (%)	Change (%)[a]
Classification	67.2	76.3	**+9.1%**
Interpretation	72.8	75.2	**+2.4%**
Processes	70.8	75.3	**+4.5%**
Definition	78.6	75.1	**−3.5%**
Factual recall	86.2	87.0	+0.8%
Overall change	75.1	77.7	**+2.6%**
Lower-order thinking[b]	82.4	81.1	−1.3%
Higher-order thinking[c]	70.3	75.6	**+5.3**%

[a] Change scores in boldface are statistically significant at $p < 0.05$.

[b] Lower order thinking questions are those that test students' abilities to recall definitions and simple facts.

[c] Higher order thinking questions are those that test students' abilities to classify objects, interpret data, and extrapolate the results of processes.

Generalizability

This analysis tracks the learning of students in one specific case-based introductory geology course. This particular course is typically composed of 25 students per section and is taught at a small, selective liberal arts college. Since this class qualifies as part of Westminster College's core Liberal Education program, the student population is a mix of both science and non-science majors and has demographics very similar to the college as a whole (54% female, 42% out of state, 23% students of color). Classes meet twice a week for 75 min. Since there is no dedicated lab time for this class, class sessions are a mix of traditional lectures broken up with in-class demonstrations.

While this class is obviously not representative of all college and university level introductory geology classes, there is good reason to believe that the case-based curriculum is broadly generalizable across a wide range of class formats. The fact that I primarily use a traditional lecture format for the class means that this curriculum could easily be used for classes with much larger enrollments. Furthermore, while the order of topics covered in this class is different from the order of topics covered in a traditional geology class, it is worth reiterating that the topics themselves are still the same. As a consequence, existing lab courses could conceivably be transformed into case-based courses without significant change to existing lab activities.

One way in which faculty at other institutions may wish to alter this curriculum is through the actual selection of cases. I chose the Great Salt Lake as the case study for the first part of the class, not only because it is an exceptional case study in weathering, hydrological cycling, and chemical sedimentation, but also because it is a local case. There is ample room within this curriculum to choose case studies that fit particularly well either with an institution's geography, or perhaps with a larger departmental learning goal. As examples, a school in the northeast might explore the consequences of acid rain in the Adirondacks as its first case study. On the other hand, a school whose introductory geology class is part of an environmental studies major, rather than a geology major, may prefer to use the depletion of the Aral Sea. Either of these cases would provide opportunities to teach the same concepts as the Great Salt Lake.

DISCUSSION

Students who took introductory geology using a case-based curriculum performed better than students who took the same class, from the same professor, with the same available resources, using a traditional curriculum. Furthermore, these students also showed unanimous improvement in their understanding of geological concepts on post-tests relative to pre-tests. What makes this degree of learning even more remarkable is the type of questions that drives the trend.

The majority of student improvement comes from questions that test their abilities to classify objects, synthesize information, and extrapolate from known processes. These are all higher-order thinking skills (*sensu* Bloom, 1956). While there is a small increase in students' ability to recall factual information, it is not statistically significant. This demonstrable improvement in higher-order thinking skills indicates that under a case-based curriculum, students are not only learning more about the earth, they are also learning to think more deeply about the earth. Given these generally positive learning outcomes, even the statistically significant drop in students' ability to define geologic terms may not necessarily be a troubling result.

One possible explanation for this drop in definitional ability is the fact that students are simply devoting more of their time and energy to learning concepts and processes than to learning terms. This interpretation would be consistent with the increase in higher order thinking skills described above. One other possibility is the fact that I have changed the status of the textbook in my class from required to recommended. In informal discussions that I have had with many of the students in my class, I have learned that very few of them actually purchased the textbook (which currently sells for over $130) now that it is no longer required. While students still have access to my lecture notes, those notes are organized by geographic question and do not come with a glossary.

If the drop in students' ability to define terms is, in fact, related to either the absence of a required textbook in my class or to a greater emphasis on learning concepts, then the lack of a change in students' ability to recall factual information actually becomes a bit of good news. If students are absorbing classroom material just as well, without a textbook to reinforce the concepts, then that suggests that they are more engaged with that material as it is being presented. I have recently learned about a service available from some textbook publishers to print custom textbooks with chapters pulled from several sources and arranged in whatever order the instructor desires. I am planning on using one of these custom books in my class the next time I teach it to see if there is any effect on students' ability to define terms.

Previous studies of student engagement and learning in other introductory science classes, especially introductory physics classes, have demonstrated similar results to those presented here (e.g., Hake, 1998). When students approach science as a set of questions rather than as a body of facts, it increases their engagement, their curiosity, and therefore, their learning. Philosophically, there is one additional reason to approach any introductory science class from a case-based perspective: It models how science works. Geologists did not read the theories of plate tectonics, seafloor spreading, or deep time in a book and then go out to apply them to the earth. We explored the earth and used the results of those explorations to create theories. By teaching introductory geology classes in the same way, we can introduce students not only to the factual basis of geology, but also to its history and inherent appeal.

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