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HOW OLD IS THE EARTH? AN EXPLORATION OF GEOLOGIC TIME THROUGH PLACE-BASED INQUIRY

Geologic time is fundamental to the study of the Earth and life sciences, but it is an abstract and difficult concept for students to master. We predict that place-based inquiry, in which students directly engage with authentic and meaningful local landscapes while interpreting physical evidence for geologic time, will be at least as effective as more orthodox expository methods in imparting geoscience content knowledge, such as the concept of geologic time. This outcome, coupled with the enhanced relevance and interest inherent in the method, would favor its use in naturally and culturally diverse settings such as the Southwest United States. As a preliminary test of the effectiveness of place-based inquiry, we designed and administered two 2-part inquiry lessons on relative and absolute geologic time, based on Arizona landscapes and rocks, to 52 in-service middle- and high-school math and science teachers enrolled in an experimental graduate course in biology, geology, and mathematics. The teachers' knowledge of geologic time before and after the lessons was assessed using the Geoscience Concept Inventory, a valid and reliable survey. We analyzed pre-test and post-test means with a non-directional dependent samples t-test and reject the null hypothesis of no mean differences, $t(49) = 5.35$, $p < .01$. We conclude that there is a significant gain in the teachers' content knowledge related to geologic time before the inquiry lessons (Mean = 11.66, SD = 2.93) and after the inquiry lessons (Mean = 9.74, SD = 3.57). The teachers who participated in the class reported that the place-based lessons were particularly engaging and ranked them among their favorites for the experimental course. Place-based teaching methods in geoscience merit further study at the undergraduate and graduate level.

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Introduction

This study was motivated by the development of a graduate-level in-service course titled *Connecting Biology, Geology, and Mathematics* (CBGM), one of five implemented under a Mathematics-Science Partnership project funded by the National Science

Foundation. CBGM and its companion courses are intended to promote inter-diffusion and mutual enhancement of secondary-school science and mathematics, by modeling the teaching of relevant scientific topics in an authentically quantitative and inquiry-driven manner. As they are capstone courses designed for teachers with considerable prior preparation and teaching experience in their own disciplines, each focuses on a meaningful but economical set of topics related by a common theme. For CBGM, that theme is geological and biological evolution and their ensuing natural diversity.

The teaching of evolution in schools is hampered by political controversy (e.g., Zimmerman, 1987) and by negative affective responses to the implications of the theory (Brem, Ranney, & Schindel, 2003; Hahn, Brem, & Semken, 2005), but also by the considerable difficulty teachers have in grasping the scope of geologic time (Trend, 2000), over which crustal, environmental, and biological evolution have taken place. Our present understanding of "deep time" (McPhee, 1981) is bolstered by abstract principles of physics and chemistry manifested in precise measurements of natural timekeeping processes, such as the exponential decay of radioactive trace elements in rocks. These types of measurements are collectively referred to as "absolute" geologic dating. This quantitative record of the history of Earth and life is substantive and impressive, but the means of obtaining it are likely to be viewed as a "black box" by most teachers.

However, the concept of deep time initially emerged from a more concrete and pedagogically accessible idea: evidence in landscapes all around us indicates that Earth has been profoundly changed by processes, such as uplift and erosion, which must operate at vanishingly slow rates (Hutton, 1795; Lyell, 1830/1990; Zen, 2001). This idea is usually referred to as uniformitarianism or uniformity. As evinced by the way geologic time is presented in the most used introductory textbooks (e.g., Grotzinger, Jordan, Press, & Siever, 2007), a common pedagogical approach is to begin by using uniformitarianism to interpret relative sequences of geologic events recorded in layered rocks and landforms ("relative" geologic dating), lead students to make inferences about the scale of time needed to effect these processes, and only then introduce absolute geologic dating to assign numerical values to that time scale. This same sequence was employed in CBGM, though not in the expository lecture format that frequently accompanies the use of these textbooks.

Connection to Inquiry Teaching and Learning

As noted above, CBGM is an inquiry-driven course. Inquiry is a fundamental part of both the teaching and learning aspects of the *National Science Education Standards* developed by the National Research Council (NRC). The *Standards* call for teachers to "focus and support inquiries while interacting with students" and states that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (National Research Council, 1995, p. 31). Students who actively participate in their own learning show gains in their assessment scores and critical thinking abilities as well as often displaying an increased excitement in the process of learning in general (National Research Council, 2000). CBGM lessons model scientific inquiry by means of the learning-cycle method, a three-stage process of exploration, explanation, and application shown to be effective in teaching scientific content knowledge and in enhancing scientific reasoning (Karplus, 1974; Lawson, Abraham, & Renner, 1989; Marek & Cavallo, 1997; Lawson, Jensen, & Oehrtman, in press).

Uniformitarianism and relative geologic dating readily lend themselves to inquiry learning in the field, by means of virtual field trips (e.g., Geological Society of America & Palmer, 1989), or by briefer activities such as learning-cycle interpretation of landscape images (Reynolds & Peacock, 1998). Course logistics precluded the use of field trips in CBGM, but the inquiry lessons on geologic time simulated field environments as closely as possible with rock specimens, maps, landscape photos, and animated flyovers (Simkin, 2006).

Sense of Place and Place-Based Teaching and Learning

Any locality that has become imbued with meaning by direct or indirect human experience with it is a place (Tuan, 1977). The diverse meanings that places hold for people, and the emotional attachments people develop for meaningful places, are collectively referred to as sense of place (Relph, 1976; Brandenburg & Carroll, 1995). Sense of place is thus both cognitive and affective. Place-based teaching is a situated approach that consciously engages the senses of place of students and instructor through rich use of local examples or case studies, synthesis of cross-disciplinary and cross-cultural knowledge of places, and experiential learning (Gruenewald, 2003; Sobel, 2004; Semken, 2005). Hence, place-based teaching connects students with their community and region, models respect for the cultures and values of the local population, and is engaging and relevant. It has been proposed that place-based teaching of natural science will improve retention of diverse students, particularly members of indigenous or long-rooted communities with rich senses of place (Cajete, 2000; Riggs, 2004; Semken, 2005; Chinn, 2006; Gibson & Puniwai, 2006), such as American Indians and Chicanos in the Southwest United States. As some of the schools participating in our Mathematics-Science Partnership serve these student populations in the Phoenix metropolitan area, we modeled place-based teaching in CBGM by situating the inquiry lessons on geologic time in regional places familiar and meaningful to most Arizonans, including Grand Canyon, Monument Valley, Meteor Crater, and the San Francisco Mountains.

Research Objectives

The study described in this paper was conducted during the spring 2006 pilot offering of CBGM, and carried out in parallel with other studies of learning-cycle inquiry on scientific reasoning and teachers' ability to integrate science and mathematics (Lawson, Jensen, & Oehrtman, in press). The effectiveness of inquiry science teaching has been repeatedly demonstrated for different disciplines and settings (e.g., Lawson, Abraham, & Renner, 1989). More specifically relevant to this study, Crawford, Zembal-Saul, Munford, and Friedrichsen (2005) showed that inquiry teaching improved pre-service teachers' understanding of natural selection and evolution.

However, the effectiveness of place-based science teaching in improving science content knowledge, compared to other teaching methods, is only now being scrutinized (Semken, 2005; Semken & Butler Freeman, 2006 and in press). We predict that a place-based approach to geoscience teaching, in which direct engagement with known and meaningful places provides cognitive and affective scaffolding (i.e., leverages and enhances a student's sense of place), will be at least as effective as more orthodox expository methods in imparting geoscience content knowledge, such as the concept of geologic time. This outcome, coupled with the enhanced relevance and interest inherent in the method (Gruenewald, 2003), would favor its use in naturally and culturally diverse settings such as the Southwest United States. The approach models pedagogy that the CBGM teachers can subsequently employ in their own classes.

The specific objectives of this study were to (1) design and test two 2-part lessons to teach relative and absolute geologic dating to in-service teachers in CBGM through place-based, learning-cycle inquiry, and (2) measure and compare the teachers' knowledge of the concept of geologic time and related geoscience concepts before and after the sequence of lessons, using a valid and reliable nationally-normed survey instrument, the Geoscience Content Inventory (Libarkin & Anderson, 2005). Control groups could not be used in this experiment because of project goals, and enrollment and staffing limitations.

Lesson Design and Implementation

The participants in the spring 2006 study comprised 52 in-service middle-school and high-school mathematics and science teachers. The two 2-part lessons on geologic time, each three hours in duration, were offered during the eighth through eleventh weeks of a fifteen-week semester. The prior lessons addressed scientific reasoning, genetic variation, and biological diversity, and subsequent lessons presented population growth. Table 1 is an outline of the geologic time lessons.

Table 1

Place-based Inquiry Lessons on Geologic Time in the Spring 2006 CBGM Course

Lesson	Learning cycle type (Lawson, 2002)	Week	Description
What histories can we read in the Earth? (relative dating and uniformitarianism)	Empirical-abductive	8	Explore four Arizona landscapes (Monument Valley, Hunters Point, San Francisco Volcanics, Meteor Crater) using maps, images, movies, and rock specimens; generate and test causal hypotheses; determine relative geologic sequences; introduce uniformitarianism.
		9	Explore two additional landscapes (Grand Canyon and Black Mesa) and compare geologic evidence from all places studied with processes operating today; quantitatively compare different processes of formation; make inferences about geologic time and the age of the Earth.
How old is the Earth? (radioactive decay and absolute dating)	Descriptive	10	Explore natural radioactivity in rock specimens from the Arizona study landscapes with Geiger counters; model radioactive decay by flipping coins and generate exponential decay curves.
		11	Analyze experimental decay curves to derive the exponential function and radiometric dating equations; apply these equations to isotopic data from Arizona rocks and meteorites; calculate absolute ages of these rocks and of the Earth.

The first lesson “What histories can we read in the Earth?” was organized to enable teachers to first discover how rocks and features in local places formed and evolve. They discovered clues within the landscapes that indicate different stages of development and dramatic environmental changes (e.g., fossiliferous marine-derived rocks exposed in the high desert of northern Arizona, indicating that the region was once beneath a sea). The teachers interpreted these changes in the context of their familiarity with rates of present-day processes of change, such as erosion and volcanism, and formulated hypotheses about the causes and relative ages of the landscapes.

The teachers made mathematical calculations to test their hypotheses. For example, among a number of mechanisms teachers proposed to explain why fossil seashells occur embedded in rocks atop Black Mesa, Arizona, at 2300 meters elevation, were a catastrophic global flood and the gradual uplift of the region from sea level. Calculation of the volume of water needed to flood the Earth to that elevation indicated that it would require 62% more water (by volume) than is presently contained in all of the oceans, which cannot be accounted for in the present terrestrial hydrosphere, nor removed by any known physical mechanism. Gradual uplift of Black Mesa at rates like those measured by surveying at young mountains today is physically plausible, but would require millions of years. These exercises enabled the teachers to recognize that enormous spans of time must have passed for Arizona’s present landscapes to evolve, before they dealt with the mathematics and chemistry of the more abstract methods of measuring those intervals. This was accomplished in the second lesson, “How old is the Earth?”, in which teachers simulated the decay of radioactive atoms with a safer and more familiar analogue, coin-flipping, then deconstructed their experimental decay curves to discover the exponential function that describes the process.

Throughout, teachers leavened their small-group and full-class discussions with dialogues of personal experiences in the places under study, and with expressions of the excitement derived from learning the “stories behind the scenery.” This self-identification with the lesson and its subject, termed “leveraging sense of place” (Lim & Calabrese Barton, 2006), is characterized by a mix of cognition and affect, and was observed to help the class maintain a high level of enthusiasm and engagement throughout each three-hour session.

Pre- and Post-Testing of Content Knowledge

To measure changes in teacher knowledge of and related to geologic time, we used the valid and reliable Geoscience Content Inventory (GCI) of Libarkin and Anderson (2005). The GCI tests understanding of fundamental concepts in geology and related concepts in physics and chemistry of the Earth. It provides a means not only for an instructor to measure gain after an intervention, but to compare that gain to a national baseline established from GCI measurements in 32 diverse institutions nationwide (n = 930; Libarkin & Anderson, 2005).

The GCI consists of a 73-item test bank validated by analytical techniques including item response theory (Rasch analysis) and classical test theory (Libarkin & Anderson, 2005). For this study, a 15-item subtest, consisting mostly of questions related to the concept of geologic time, was selected from a list of validated item combinations. One limitation of the GCI for this study was that the subtest items deal primarily with absolute geologic dating. We therefore also selected three items from an experimental survey of student conceptions about sedimentary processes and landscape evolution (Busch, 2004) to test knowledge of relative geologic dating and sequences of geologic events. The 15-item GCI subtest and the three additional items were administered as a pre-test before the start of the first geologic time lesson in week 8, and as an identical post-test after the last geologic time lesson in week 11.

Results

In this study, 65.38% of the teachers scored higher on the 18-item post-test than on the pre-test. Most of the teachers (n = 34) improved their scores by three points (Mean = 3.15, SD = 2.11). Of the remaining teachers, 15.38% (n = 8) showed no change in score from the pre- to the post-test, and 15.38% (n = 8) scored lower (five scored one point lower and three scored two points lower) on the post-test than on the pre-test. Two teachers did not complete the post-test. Based on a non-directional dependent samples t-test, we reject the null hypothesis of no mean differences, t (49) = 5.35, $p < .01$. We conclude that there is a significant difference in the teachers' geoscience content knowledge before (Mean = 9.74, SD = 3.57) and after the place-based inquiry lessons (Mean = 11.66, SD = 2.92). We are 95% confident that the interval 1.20 to 2.64 contains the true population mean difference. There is a high correlation of 0.72. Therefore, the teachers completed the place-based inquiry lessons with significantly improved knowledge about geoscience concepts in general, and about geologic time specifically.

Mean scores from the fifteen GCI items in the pre- and post-tests were also analyzed separately for comparison with national baseline mean GCI scores. Because the national means are calculated from the results of a range of different GCI subtests of varying difficulty, it was first necessary to convert raw GCI scores (R_{GCI}) on a scale of 1 to 15 points to scaled percentage scores (S_{GCI}), using a formula provided by Libarkin and Anderson (2006):

$$S_{GCI} = 16.76 + 4.30R_{GCI} + 0.115(R_{GCI}-7.5)^2 + 0.042(R_{GCI} - 7.5)^3 - 0.0017(R_{GCI} - 7.5)^4$$

The scaled results of GCI pre- and post-tests in CBGM are compared to the national baseline values in Table 2.

Table 2

Comparison of Pre- and Post-Test Scaled GCI Mean Scores (S_{GCI}) for CBGM (Place-based Inquiry) Teachers and for Introductory Geology Students Nationwide

	CBGM Teachers (n = 34)	Students nationwide (n = 930; Libarkin & Anderson, 2005)
Pre-Test Mean S_{GCI}	51.40 ± 16%	42.2 ± 12%
Post-Test Mean S_{GCI}	58.76 ± 15%	45.8 ± 13%

Clearly, the in-service teachers began the lessons with greater geoscience content knowledge than that of the average introductory student nationwide. This is unsurprising given the difference in education and experience between the two groups. However, the mean pre-test GCI score for the teachers still represents little more than half of the geological content knowledge (including the concept of geologic time) considered fundamental by the geoscience community. Although the CBGM teachers achieved a statistically significant gain from the GCI pre-test to the GCI post-test, it is not meaningful to determine if the differences in the means for the two groups are statistically significant.

For the three relative dating items taken from the study by Busch (2004), based on a non-directional dependent samples t-test, we reject the null hypothesis of no mean differences, $t(49) = 4.01$, $p < .01$. We conclude that there is a significant difference in the teachers' content knowledge measured by these items before (Mean = 1.90, SD = 1.02) and after the place-based inquiry lessons (Mean = 2.44, SD = .76). We are 95% confident that the interval .269 to .811 contains the true population mean difference. There is a moderate correlation of 0.46. The CBGM teachers completed the place-based inquiry lessons with significantly improved knowledge about relative geologic dating.

In an end-of-semester evaluation, the teachers were asked to identify the lessons they thought were the best of the seven presented in CBGM, and comment on their selections. As many answered this open-ended question with more than one selection, there were 75 responses in total. The relative dating lesson "What histories can we read in the Earth?" and an opening inquiry lesson were identified as the best by the largest percentage of responses (22.7%). The absolute dating lesson "How old is the Earth?" was named as the best by the fourth-highest percentage (14.7%). Many of the reasons the teachers gave for their favorable ratings related directly to the place-based nature of the lessons (i.e., relevance to local landscapes and applicability to their own classrooms); other reasons cited were the novelty of the content (many CBGM teachers had little or no previous exposure to the Earth sciences), instructor passion, and fun.

Discussion and Recommendations

Our preliminary study shows that a Southwest place-based focus can be combined with learning-cycle inquiry teaching in geoscience to yield an effective and more relevant means of teaching the abstract concept of geologic time to in-service teachers. The comparative effectiveness of the place-based inquiry approach versus more traditional methods, and the relationship between enhanced understanding of geologic time and understanding of evolutionary theory, merit further study in larger controlled experiments.

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