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Testing the effects of prior coursework and gender on geoscience learning with Google Earth

Janice Gobert*
Social Sciences and Policy Studies, Worcester Polytechnic Institute, 100 Institute Road, Worcester, Massachusetts 01609-2280, USA

Steven C. Wild*
Old Dominion University, Physics Department, 4600 Elkhorn Ave., Norfolk, Virginia 23529, USA

Lisa Rossi*
Social Sciences and Policy Studies, Worcester Polytechnic Institute, 100 Institute Road, Worcester, Massachusetts 01609-2280, USA

ABSTRACT

Two sets of learning activities in Google Earth were developed for use by geoscience majors and non-science majors. The first activity aimed to foster undergraduate students' understanding of the geography and basic geology of Iceland. We tested the efficacy of this activity for learning with 300 undergraduates from a university in the southeastern part of the United States. In terms of post- versus pre-test scores we found: (1) overall learning gains when collapsing over type of prior knowledge and gender, (2) no differences in learning gains when comparing those with prior coursework in geology or geography to other students without such prior coursework, and (3) no differences in learning gains when comparing males and females. In terms of items completed during the lab exercise, again we found no differences by prior coursework (prior geology, prior geography, or none), and no differences by gender. Lastly, moderate positive correlations were found between students' pre-test and post-test scores, as well as between students' embedded lab scores and post-test scores.

For the second activity, we developed a laboratory activity about the classic Tonga region of the west Pacific in order to support undergraduate students' understanding of: (1) the physical geography of the Tonga Subduction System, (2) the dynamic geological processes involved in plate movement, subduction, magmatic arc evolution, and trench rollback, and (3) geological processes resulting from subduction, including volcanism, and earthquake formation. Using the program called Sketch-Up, we created 3-D COLLADA (three-dimensional COLLAborative Design Activity) models

*jgobert@wpi.edu; swild@odu.edu; lrossi@wpi.edu.

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that are viewable as four-dimensional animations in the Google Earth API (application programming interface; a web-based version of Google Earth) to help demonstrate several geophysical processes. These animations potentially have a wide range of learning application from basic to more abstract ideas. Specifically, the learning objects created involve the Pacific Plate subducting underneath the Australian Plate in the Tonga Region. These are designed to help show subduction, active and dormant volcanoes, back-arc spreading, trench rollback, and migration of the tear point that marks the northern termination of the subduction system. We tested the efficacy of this activity with 127 undergraduates from a university in the southeastern part of the United States. In terms of post- versus pre-test scores we found: (1) overall learning gains when collapsing over type of prior knowledge and gender, (2) no differences in learning gains when comparing those with prior coursework in geology or geography to other students without this prior coursework; and (3) no differences in learning gains when comparing males and females. For the lab activity itself, we found no differences by prior coursework (geology and/or geography versus none), but found a gender difference favoring males; however this learning did not show up as statistically significant at post-test (as previously mentioned). Lastly, moderate positive correlations were found between students' pre-test and lab scores.

Data is discussed with respect to Google Earth's utility to convey basic geoscience principles to non-geology undergraduates and its potential impact on public understanding. This is important and aligned with many current educational reform efforts (the American Association for the Advancement of Science, National Science Education Standards), which call for broader scientific literacy.

INTRODUCTION

Learning in this Domain: Why is it Difficult?

The domain chosen for this study is plate tectonics, the lead paradigm for understanding the origin and evolution of Earth's surface features including continents, oceans, and island arcs. This is a difficult topic to learn both because of the hidden mechanical processes, which are outside our direct experience, and because it involves several different types of knowledge including spatial, causal, and dynamic knowledge (Gobert and Clement, 1999; Gobert, 2000). Specifically, conceptual understanding in this domain requires understanding the spatial arrangement of the various material components of the earth (i.e., spatial/static information) as well as understanding the movements within these layers and their dynamic causes (i.e., primordial core) and radioactive sources of heat (i.e., mantle) that must escape Earth's deep interior (KamLAND Collaboration, 2011), convection of solid material through the mantle (Wilson, 1973), plate movements, divergence and convergence at plate boundaries, and the interaction of surface plates with deep mantle plumes (Morgan, 1972). In addition to acquiring two types of knowledge (spatial/static and kinematic/dynamic), several concepts need to be integrated into a complex causal chain to build a rich, 4-D mental model of the system (Gobert and Clement, 1999; Gobert, 2000). From these mental models, predictions and inferences can be made about the system's behavior: in the case of plate tectonics, explaining or depicting locations of earthquakes and volcanoes, sea-floor spreading, mountain building, and island-arc evolution.

Among the most difficult concepts that we present to students are (1) plate-plume interaction as in Iceland (Ito and Lin, 1995), and (2) trench rollback as in the Tonga region (Isacks et al., 1968). Iceland stands high above sea level because it marks the intersection of the Mid-Atlantic Spreading Ridge and a deep mantle plume emanating from the core-mantle boundary. Students thus have to visualize two processes with very different length and time scales. Time scale is particularly difficult to understand, even for graduate students of geology (Jacobi et al., 1996). Tonga is the type locality for the process of trench rollback whereby the line along which the plate bends into a subduction zone migrates in the opposite direction to the material of the plate (Uyeda and Kanamori, 1979; Rosenbaum and Lister, 2004; Moores and Twiss, 1995). At Tonga, for example, the rocks of the Pacific plate move westward while the trench marking the initiation of subduction migrates east.

Relevant Work on Learning in Geoscience

Google Earth, a fairly new program (version 1 was released in 2005), constructs pictures of Earth by downloading satellite data from a remote terabyte server (Lisle, 2006) and rendering them on a virtual globe in real time. The program is interactive so that the location and size of the region viewed is under full control of the learner/user; the user can zoom in, pan, and tilt the terrain from any desired viewpoint, and the surface imagery communicates information in a format that is more intuitive and realistic than paper maps and cross-sections (Whitmeyer et al., 2010). This last feature makes them useful for learning and reasoning for experts in the domain, as well as for students and lay people, e.g., non-science majors (this is addressed more fully later in the paper).

It is argued that Google Earth is a tool that can help build scientific literacy on a broad scale because it and other geotechnologies are ways to give citizens basic knowledge of geography (Sanchez, 2009) and geoscience (Thompson et al., 2006). Secondly, in addition to basic content knowledge, some researchers claim that working in Google Earth can hone one's data analysis and interpretation skills, which, many argue, are becoming increasingly important in scientific and industrial fields. As an extension to this latter point, it has been further argued that the ability to use images and spatial technologies is necessary in order to participate in modern society (Bednarz et al., 2006) since information and data tends to be displayed in spatially oriented formats.

To date, there have been a fairly large number of studies that address learning in geoscience, but most of these have been conducted with a pre-college population (Libarkin and Anderson, 2005), and studies on college students or other adults only emerged within the last decade or so (cf. DeLaughter et al., 1998; Trend, 2000; Libarkin, 2001; Libarkin et al., 2005; Dahl et al., 2005). Amongst the research on this topic with an adult population, the research that is most closely related to the present research is the research on learning with visualizations in geoscience (cf. Hall-Wallace and McAuliffe, 2002; Whitmeyer et al., 2009; Thompson et al., 2006).

With respect to training students in geoscience specifically, recent reform efforts emphasize the need to utilize technology in teaching and learning (Stout et al., 1994; National Research Council, 1996), which has translated into greater demand for technology-based teaching methods (Cruz and Zellers, 2006). In parallel, there also have been demands for greater instructor accountability for students' learning at all levels, as decreasing enrollment trends continue in the STEM (science, technology, engineering, and mathematics) disciplines (McConnell et al., 2006). Although learning with Google Earth has been touted as having great potential for improving students' knowledge about geological phenomena, spatial skills, problem-solving, etc., and the fact that, intuitively it appears to have many affordances for geoscience learning (Cruz and Zellers, 2006; Whitmeyer et al., 2009), there are relatively few studies that either characterize the learning processes that students engage in while learning with Google Earth, or that address the efficacy of learning with Google Earth.

Characterizing Learning Processes with Google Earth

It has been noted that Google Earth (referred to herein as GE) offers a benefit over more traditional GIS (geographic information systems) in that GE can be implemented into classrooms at any level because it has relatively few tools and thus less overhead for the teacher in learning it (Patterson, 2007; Bodzin et al., 2012). In terms of the utility of GE for college professors and high school teachers, GE only requires a basic knowledge of scripting languages in order to construct materials (Whitmeyer et al., 2010). For example, GE has been used in high school classrooms for virtual exploration of geologic features to support students' understandings of geological processes (Fermann, 2006; Stahley, 2006). Similarly, Sanchez (2009) describes implementations in which a teacher developed a geological map that encompasses layers of data about earthquakes and volcanoes. Here, it was suggested that these implementations help students to identify different aspects of oceanic crust formation and understand the mid-ocean ridge system. Lastly, Patterson (2007), who has used GE for middle school instruction, suggested that GE's interactive exploration capacity helps students understand the spatial context of their location and engage in spatially oriented learning in an entertaining and meaningful manner.

Studies that have Addressed the Efficacy of Google Earth

One study compared GE to traditional textbook materials for undergraduates' learning of landforms (Cruz and Zellers, 2006). Findings revealed that students in the GE condition gained deeper understanding of the content compared to those in the traditional textbook condition. Furthermore, those students who had previous exposure to GE performed better than those who did not. Similarly, Martin and Treves (2008) showed that GE is effective to help students and the general public (i.e., non-majors) visualize both scientific data and science content in 3-D. Martin and Treves (2008) stressed the importance of promoting active learning and dissuaded the development of "flashy" 3-D animations, since students, who by definition lack expertise, do not know what is salient in order to engage in knowledge acquisition from information sources (Gobert, 2005a). Bodzin and Cirucci (2009) similarly noted that resources such as GE, when used in conjunction with appropriately designed instructional materials, show much potential in promoting students' spatial thinking.

In two innovative studies in which students constructed their own materials using GE, learning gains were obtained. First, Whitmeyer et al. (2009) had undergraduates use handheld computers to collect lithologic and structural data and then analyze it in order to construct geologic maps of their field areas. This approach, according to the authors, familiarizes students with GE tools, and in turn, can be useful in improving students' interpretations of field geology. Similar results have been found in which students constructed their own representations of geoscientific phenomena (Gobert and Clement, 1999; Gobert, 2000; Gobert and Pallant, 2004; Gobert, 2005b). In another study, Thompson et al. (2006) showed students how to create their own content in GE. Here, not only did students learn important design elements and skills, but students also reported that these skills were amongst the most important that they learned in their geoscience program.

These last studies described address an important issue underlying learning with visualizations; that is, that deep learning with visualizations typically requires accompanying materials, scaffolds, etc., in order to support and guide students in their learning processes. This is critical since students often do not know what is salient within these rich visual information sources (Lowe, 1993) because they present all information simultaneously (see Larkin and Simon [1987] and Gobert [2005a] for more on this topic).

RATIONALE

In our project, we address the learning gains for two different units developed in GE. In particular, in each study we address the efficacy of those with prior coursework in geology and geography, compared to non-majors with no prior coursework in these domains. Secondly, although it was not part of the original design of the research, we compare the learning gains of both males and females, since many studies have shown that females lag behind males in their learning of geoscience concepts due to their inherent spatial nature and females' oft-reported diminished spatial skills (Kahle et al., 1993; Dabbs et al., 1998; Burkham et al., 1997; Britner, 2008).

STUDY 1

Purpose

In the first study, we developed a GE activity to support students' understanding of the geography and basic geology of Iceland. We tested the efficacy of this activity in terms of post- versus pre-test scores for: (1) overall learning gains as measured by pre- and post-tests, (2) differences in learning gains when comparing those with prior coursework in geology or geography to other students without such prior coursework, and (3) differences in learning gains when comparing males and females. Lastly, we also compared students' learning on the lab activity itself (i.e., the pedagogical activities that were completed as part of the lab).

Method

Participants

A total of 225 undergraduate students from a southeastern university participated in this study as part of their coursework[1]; age data for the participants was not collected. All students were part of the same large lecture; there were nine sections of the lab that corresponded to the lecture from which our data was drawn.

Materials

Pre-Test/Post-Test

The pre-test and post-test consisted of the same set of 10 questions on basic geological and geographical knowledge of Iceland as well as one question asking about prior experience studying this topic (Table 1). Of these questions, nine were multiple choice, and one asked participants to locate Iceland on a provided map. The pre-test served to determine a baseline of prior knowledge that a participant had coming into the activity, while the post-test determined what knowledge was gained as a result of participating in the lab activity (Table 2). All items were developed by experts in the area of geoscience as part of three ongoing projects (NSF-CLLI #0837040, De Paor and Whitmeyer, 2008; NSF-GEO #1034643, De Paor and Whitmeyer, 2010; NSF-DUE #1022755, De Paor et al., 2010). Some examples of items on the pre- and post-test are given below; the full set of items is included in Appendix A[2].

TABLE 1. AN EXAMPLE OF TWO QUESTIONS FROM THE PRE- AND POST-TEST, ICELAND ACTIVITY

Q8 What is the principle rock type seen in Iceland
- (i) limestone
- (ii) basalt
- (iii) granite
- (iv) marble

Q9 Which best describes the geological origins of Iceland?
- (i) Iceland sits on top of both a deep mantle plume and a divergent plate boundary.
- (ii) Iceland is a fragment of continental crust, like Britain and Ireland, that detached from the European margin during North Atlantic spreading.
- (iii) Iceland is a volcanic island arc forming above a subduction zone.
- (iv) Iceland is a huge floating mass of ice drifting very slowly away from Greenland.

TABLE 2. AN EXAMPLE OF A QUESTION ASKED IN THE ICELAND LAB ACTIVITY

15.1 Wait for the images to load, then drag the time slider in order to reveal the deep mantle plume under Iceland (Fig. 15).

⊗ Compare the height (thickness) of the plume and the thickness of the lithosphere:

………………………………………………………………………………….

⊗ Estimate how deep the plume extends:

…………………………………………………………………………………..

Lab Activities for Iceland

The Iceland lab activity consisted of a series of tasks that were designed to develop students' understanding of the geography and geology of Iceland. Tasks included: locating Iceland in Google Earth, specifying its relationship geographically with respect to the Arctic Circle, using the time slider to observe the

[1]Data were collected, coded, and stored in compliance with the requirements as outlined by Federal Policy for the Protection of Human Subjects.

[2]GSA Data Repository item 2012308, Appendices A and B, is available at http://www.geosociety.org/pubs/ft2012.htm, or on request from editing@geosociety.org.

horizon, asking students what they would expect to see here at the Winter Solstice, observing the landscape, geological features (e.g., rock types), and other characteristics of Iceland's urban and rural landscapes by driving around in a virtual car, observing the formation of the Mid-Atlantic Ridge by using a time slider, noting how the Mid-Atlantic Ridge is displaced across the Gibbs Fracture Zone, and observing the deep mantle plume under Iceland.

Procedure

Students initially were given consent forms, with verbal explanation, and a tracking identification number was assigned. Identification numbers were based on the course lab number, the beginning five digits, and then some digits after that given by the lab teaching assistant. Students were informed to not use their university identification numbers. Labs and pre- or post-tests with university identification numbers were not used and were removed from the study. Once the consent forms were completed and tracking identification numbers administered, each student was given a pre-test. If students finished their pre-test early, they were asked to wait quietly while others finished.

The students worked in groups of two to four depending on the lab section, with lab sections having different numbers of students. Students were encouraged, sometimes with help from instructors, to take turns working on the computers. Instructors were only allowed to help if students had technical problems but not with lab material itself. The students were informed that the lab itself would not be graded as part of their lab score, which may have had an effect on the way students answered questions or participated during lab. As students completed the labs, they were collected and the students were asked to wait for their fellow classmates to finish.

The last part of the lab consisted of the post-test. The post-test is the same as the pre-test. Each student was given a post-test and upon completion was allowed to leave the lab. No collaboration was allowed during the pre- or post-tests. The pre-test, lab activity, and post-test were all completed in one, two-hour lab period.

Data scoring

Pre- and Post-Test Scoring

The pre- and post-tests consisted mainly of multiple choice questions and were scored on a partial- or full-credit basis. A participant could earn a maximum of two points on each question for choosing the correct answer, one point for choosing a partially correct answer, and zero points for choosing an incorrect answer. Some questions had more than one possible answer worth one point, as shown in Table 3. Answer "iii" is worth two points, answers "i," "iv," or "v" are each worth one point, and answer "ii" is worth zero points.

Lab Items Scoring

The lab activity consisted of seven open response or "yes/no" questions, which were scored on a partial credit basis out of a possible one, two, or three, depending on the question. The scoring scheme for a three-point question is shown below in Table 4. Each correctly circled answer earned one point, and the open response portion was scored as zero, 0.5, or one point based on accuracy and detail.

Results

Data were analyzed to address overall learning gains from the Iceland lab, as measured by pre- and post-tests, as well as to test whether there were any learning gain differences due to prior

TABLE 3. QUESTION 2 AND ITS CODING SCHEME FOR THE ICELAND ACTIVITY

Q2 Where is Iceland relative to the Arctic Circle?	Scoring Q2	
(i) Iceland lies entirely south of the Arctic Circle.	i.	1
(ii) Iceland lies entirely north of the Arctic Circle.	ii.	0
(iii) The Arctic Circle touches the northern coast or offshore islands.	iii.	2
(iv) The Arctic Circle touches the southern coast or offshore islands.	iv.	1
(v) The Arctic Circle goes through the center of Iceland.	v.	1

TABLE 4. QUESTION 4.4 AND ITS CODING SCHEME FOR THE ICELAND ACTIVITY

4.4 Visit various parts of Iceland and record your first impressions of the country here:	
Outiside of Reykjavik, is Iceland heavily populated/developed?	⊗ [Yes / No]
Do you see a lot of large-scale agricultural or industrial plants?	⊗ [Yes / No]
How would you describe the terrain?	
undeveloped or under-developed or poor land or barren or isolated or partly farmed or grassland or tundra or equivalent	

TABLE 5. AVERAGE SCORES ON PRE-TEST BY TOTAL, GENDER, AND PRIOR COURSEWORK FOR THE ICELAND ACTIVITY

	Overall	Female	Male	Geology and/or geography	No geology or geography
Mean pre-test score	6.69	6.32	7.05	7.44	6.57
Standard deviation	2.95	2.52	3.44	3.37	2.75

coursework in geology and/or geography. Gender differences were also analyzed, although this was not part of the original design of the study. Lastly, data were analyzed with respect to learning during the lab activity itself. Each analysis is presented and described in turn. The unit of analysis here was data from each individual student.

Were there Differences by Prior Coursework or Gender before the Iceland Learning Activity with Google Earth?

First, we addressed if there were any differences on the pre-test both by prior coursework and by gender. A univariate analysis of variance was computed for each of these analyses. First, the difference between the total scores on the pre-test was not statistically different when comparing those with prior coursework to those with no prior coursework ($F = 1.838$, $p = 0.162$). Secondly, the difference on the total pre-test score was not statistically different when comparing males and females ($F = 1.890$; $p = 0.154$). See Table 5 for means and standard deviations for each of these analyses.[3]

Did the Iceland Activity Yield Differences in Overall Pre-Post Comparisons?

Next we addressed if there were differences in overall post-test scores compared to pre-test scores collapsing over both prior coursework and gender categories. A paired t-test was computed for this analysis. The difference in overall pre-test score and overall post-test score was statistically significant, [$t(224) = 13.33$, $p = 0.000$; $\bar{X}$ pre = 6.69, SD = 2.95; $\bar{X}$ post = 9.68, SD = 3.58] ($\bar{X}$—mean; SD—standard deviation); this result demonstrates that on average, students had higher scores on the post-test than on the pre-test. See Table 6 and Figure 1.

Did Type of Prior Coursework Influence Learning in the Iceland Activity?

In order to address whether there were differences between the pre- and post-test scores when comparing those with prior coursework in geology or geography to those with no relevant prior coursework, a univariate analysis of variance was conducted with the total post-test as the dependent variable and type of prior coursework as the independent variable. Pre-test was used as a covariate. The difference in post-test score by level of prior coursework was not statistically significant ($F = 2.107$; $p = 0.124$). Thus, both students with prior geology or geography coursework and those without this prior coursework learned approximately the same amount of content knowledge from the Google Earth Iceland activity, as measured by the post-test gains. The means and standard deviations can be seen in Table 7.

Were Post-Test Differences by Gender Yielded for the Iceland Activity?

In order to address whether the overall pattern observed was different when comparing males and females, a univariate analysis of variance was conducted with the total post-test as the dependent variable and gender as the independent variable. Pre-test was used as a covariate. The difference in post-test minus pre-test scores by gender was not significant ($F = 0.436$; $p = 0.647$). Thus, both males and females learned approximately the same amount of content knowledge, as measured by the post-test,

TABLE 6. OVERALL SCORES FOR PRE- AND POST-TEST FOR THE ICELAND ACTIVITY

	Pre-test	Post-test	t (df)	P
Overall score	6.69	9.68	13.329 (224)	0.000
Standard deviation	2.95	3.58		

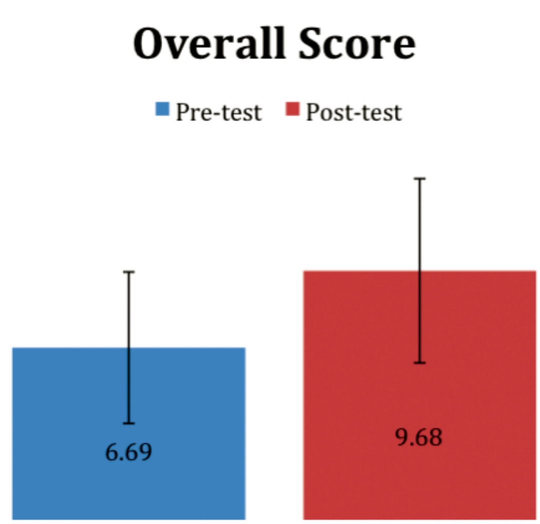


Figure 1. Overall scores on both pre-test and post-test for the Iceland activity.

[3]Although the means appear different when both comparing males and females, and when comparing those with prior relevant coursework to those with no relevant prior coursework, the standard deviations associated with these means indicate that the dispersion of scores was large in both cases, thus no statistically reliable differences were found for either comparison.

TABLE 7. AVERAGE SCORES ON PRE-TEST AND POST-TEST FOR THE ICELAND ACTIVITY BY TYPE OF PRIOR COURSEWORK

	Geology and/or geography	No geology or geography
Mean pre-test score	7.44	6.57
Standard deviation	3.37	2.75
Mean post-test score	10.78	9.57
Standard deviation	3.22	3.58

TABLE 8. AVERAGE SCORES ON PRE-TEST AND POST-TEST FOR THE ICELAND ACTIVITY BY GENDER

	Female	Male
Mean pre-test score	6.32	7.05
Standard deviation	2.52	3.44
Mean post-test score	9.37	10.21
Standard deviation	3.30	3.84

TABLE 9. AVERAGE SCORES ON THE ICELAND LAB ACTIVITY BY GENDER AND PRIOR COURSEWORK

	Female	Male	Geology and/or geography	No geology or geography
Mean lab score	4.36	4.69	4.51	4.55
Standard deviation	1.62	1.87	1.52	1.77

TABLE 10. PEARSON CORRELATION VALUES BETWEEN PRE-TEST, POST-TEST, AND LAB SCORES FOR THE ICELAND ACTIVITY

	Pre-test	Post-test	Lab
Pre-test	1	0.483*	0.101
Post-test	0.483*	1	0.291*
Lab	0.101	0.291*	1

*Statistically significant at the 0.01 level of alpha.

holding the effects of the pre-test score constant. The means and standard deviations can be seen in Table 8.

Were There Any Differences on the Lab Scores for the Iceland Activity When Comparing by Prior Coursework or by Gender?

Next we addressed the differences on the lab activity scores both by prior coursework and by gender; in other words, whether there was a difference on students' performance in the lab activity by prior coursework in geology and/or geography, or by gender. A univariate analysis of variance was computed for each of these analyses. There was no statistically significant difference found between the total scores on the lab activity when comparing those with prior coursework to those with no prior coursework ($F = 0.069$, $p = 0.934$). Additionally, the difference on the total score for the lab activity was not statistically significant when comparing males and females ($F = 1.109$, $p = 0.332$). This result demonstrates that on average, males and females scored similarly on the lab activity (see Table 9).

Is There a Relationship between the Pre-Test Scores, the Lab Scores, and the Post-Test Scores for the Iceland Activity?

In order to establish whether there was a relationship between these learning measures, a Pearson correlation analysis was conducted between all the measures, namely, the pre-test, the lab scores, and the post-test. A statistically significant correlation was found between the pre-test and post-test ($r = 0.483$, $p = 0.000$, [two-tailed]), indicating a moderate, positive relationship between the pre-test and the post-test. Another statistically significant correlation was found between the lab scores and the post-test ($r = 0.291$, $p = 0.000$, [two-tailed]). The Pearson correlation values can be seen in Table 10. No statistically significant correlation was found between the pre-test score and the lab scores ($r = 0.101$, $p = 0.132$, [two-tailed]). The scatterplots for pre-test and post-test, and pre-test and lab scores can be seen in Figures 2 and 3, respectively.

STUDY 2

Purpose

In the second study, we developed a laboratory activity focused on the classic Tonga region of the west Pacific in order to support undergraduate non-geology majors' understanding of: (1) the geographic layout of the Tonga Subduction System, (2) the dynamic geological processes involved in plate movement, subduction, magmatic arc evolution, and trench rollback, and (3) geological processes related to subduction, including volcanism and earthquake formation.

Method

Participants

A total of 138 undergraduate students from a southeastern university participated in this study[4]; age data for the participants was not collected. All students were part of the same large lecture; there were nine sections of the lab that corresponded to the lecture, from which our data was drawn.

Materials

Pre-Test/Post-Test

The pre-test and post-test consisted of the same set of 11 questions on basic geological and geographical knowledge of the American-Samoa/Tonga region as well as one question asking about prior experience studying this topic. Of these questions, nine were multiple choice, one asked for the order of four listed events, and one asked participants to locate American-Samoa/Tonga on a map that was provided to them. All items were developed by experts in the area of geoscience as part

[4]Data were collected, coded, and stored in compliance with the requirements as outlined by Federal Policy for the Protection of Human Subjects.

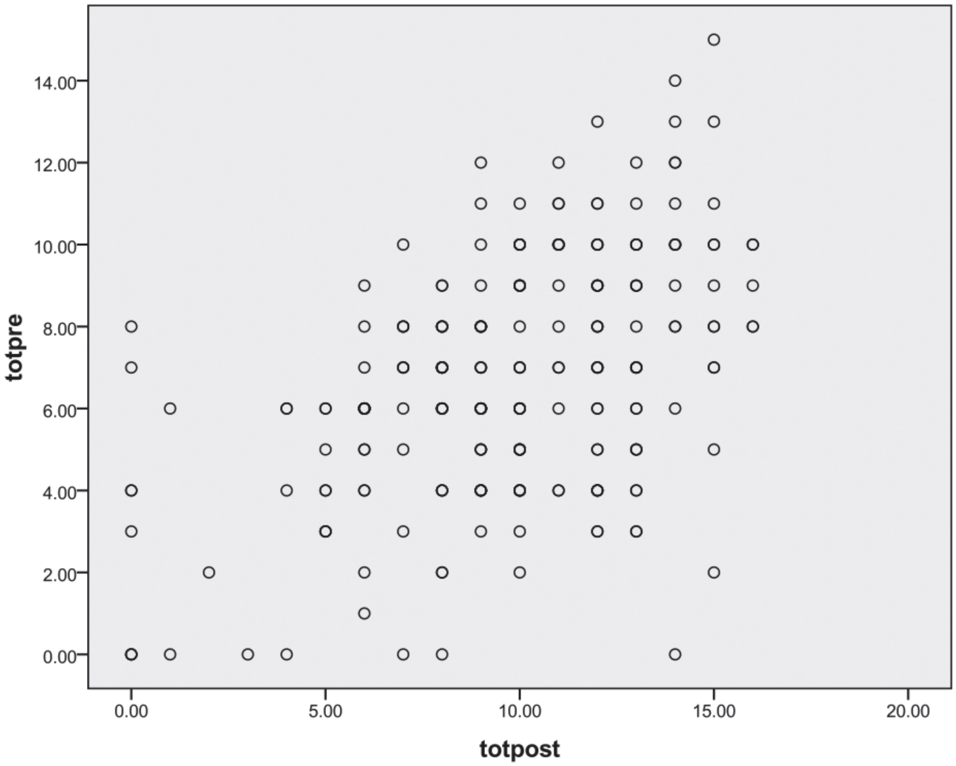


Figure 2. Scatterplot of correlation between total pre-test scores and total post-test scores for the Iceland activity.

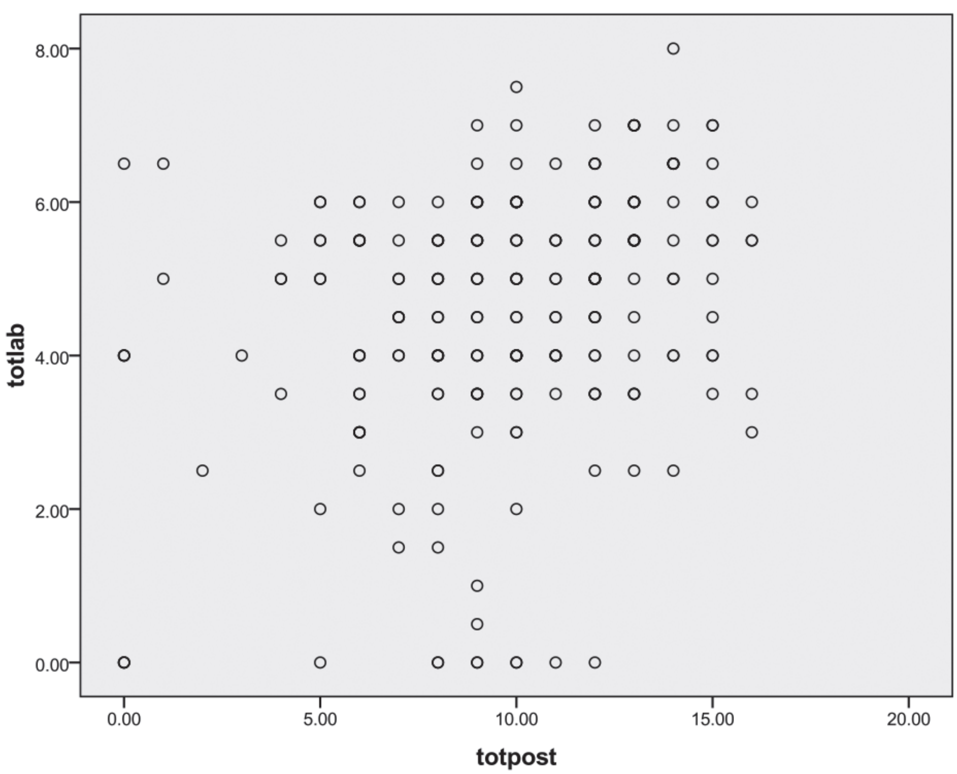


Figure 3. Scatterplot of correlation between total lab scores and total post-test scores for the Iceland activity.

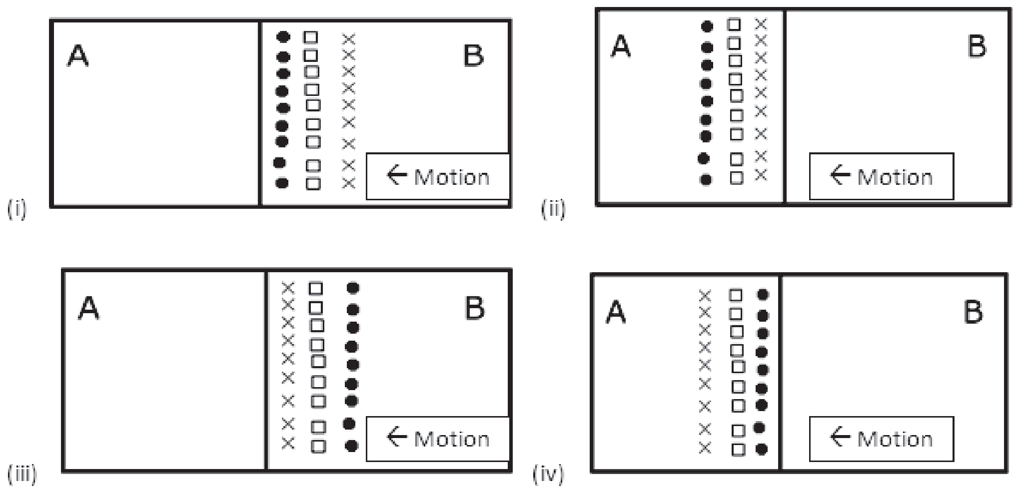
TABLE 11. A SAMPLE OF A QUESTION FROM THE PRE- AND POST-TEST FOR THE TONGA ACTIVITY

Q5 Which of the following pictures shows the earthquake pattern for the American-Samoa/Tonga region. Where **A** represents the Australian Plate and **B** is the Pacific Plate. Plate B moves under Plate A.

With ● being deep earthquakes

□ Are medium depth earthquakes

And **X** representing shallow earthquakes



of three ongoing projects (NSF-CLLI #0837040, De Paor and Whitmeyer, 2008; NSF-GEO #1034643, De Paor and Whitmeyer, 2010; NSF-DUE #1022755, De Paor et al., 2010). The pre-test served to determine a baseline of prior knowledge for each participant, while the post-test determined what knowledge gains were made after participating in the lab activity. See Tables 11 and 12 for sample items; all items are shown in Appendix B (see footnote 2).

Lab Activities for Tonga

The Tonga lab activity consisted of a series of tasks that were designed to develop students' understanding of the geology of the Tonga region in the western Pacific Ocean. Tasks included: locating the Tonga Region with respect to the Tropic of Capricorn, viewing and manipulating virtual block diagrams to observe animations of subduction, island arc formation, and trench migration, answering questions about the relative location of volcanoes and earthquakes, and answering questions about plate movement, trench formation, and plate movement and trench rollback.

Procedure

The process of gathering student performance was done in the following manner. Students initially were given consent forms, with verbal explanation, and a tracking identification number was assigned. Identification numbers were based on the course lab number, the beginning five digits, and then some digits after that given by the lab teaching assistant. Students were informed to not use their university identification numbers. Labs and pre- or post-tests with university identification numbers were not used and were removed from the study. Once the consent

TABLE 12. AN EXAMPLE OF TWO QUESTIONS ASKED IN THE PRE- AND POST-TEST FOR THE TONGA ACTIVITY

Q2 Name two features present on the surface during subduction.
1.
2.

Q3 When subduction occurs, do the volcanoes form on the down-going plate (on the east side of the trench in this case) or the over-riding plate (on the west side of the trench in this case)?

____

TABLE 13. QUESTION 6 AND ITS CODING SCHEME FOR THE TONGA ACTIVITY

Q6 The Tonga Trench's motion relative to the Pacific Plate is	Scoring Q6	
(i) Moves forward with the Pacific Plate.	i.	1
(ii) Stationary (trench does not move).	ii.	1
(iii) Moves against plate motion.	iii.	2
(iv) There is no such thing as the Tonga Trench.	iv.	0

TABLE 14. QUESTION 1 AND ITS CODING SCHEME FOR THE TONGA ACTIVITY

Q1 What is your previous experience of the geology or geography of American Samoa/Tonga	Scoring Q1	
(i) I have no significant previous study experience.	i.	0
(ii) I did a class project about the geology or geography of American Samoa/Tonga.	ii.	1
(iii) I participated in a real field trip or a holiday visit.	iii.	2
(iv) I am native to or lived in the American Samoa/Tonga region for an extended period.	iv.	3

forms were completed and tracking identification numbers administered, each student was given a pre-test. If students finished their pre-test early, they were asked to wait quietly while others finished.

The lab only had 10 MacBooks available for use, thus, students worked in groups of two to four depending on the lab section, with all lab sections having different numbers of students. Students were encouraged, sometimes with help from instructors, to take turns working on the computers. Instructors were only allowed to help if students had technical problems but not with lab material itself. The students were informed that the lab itself would not be graded as part of their lab score, which may have had an effect on the way students answered questions or participated during lab. As students completed the labs, they were collected and the students were asked to wait for their fellow classmates to finish.

The last part of the lab consisted of the post-test. The post-test is the same as the pre-test. Each student was given a post-test and upon completion was allowed to leave the lab. No collaboration was allowed during the pre- or post-tests. The pre-test, lab activity, and post-test were all completed in one, two-hour lab period.

Data Scoring

Pre- and Post-Tests

The pre- and post-tests consisted mainly of multiple choice questions and were scored on a partial- or full-credit basis. A participant could earn a maximum of two points on each question for choosing the correct answer, one point for choosing a partially correct answer, and zero points for choosing an incorrect answer. Some questions had more than one possible answer worth one point, as shown in Table 13 below. Answer "iii" is worth two points, either answers "i" or "ii" are worth one point, and answer "iv" is worth zero points.

The four choices for the question asking about the participant's prior knowledge on the subject were coded for categorization purposes as zero, one, two, or three. This scheme is illustrated in Table 14.

Lab Items Scoring

The lab activity consisted of 13 open response or matching questions, which were scored on a partial- or full-credit basis out of a possible one, two, or three, depending on the question. These questions ranged on topics covered in the activity including plate movement, subduction processes, and trench formation (see Tables 15 and 16).

Results

Data were analyzed to address overall learning gains from the Tonga lab, as measured by pre- and post-tests, as well as to test whether there were any learning gain differences due to prior coursework in geology and/or geography. Gender differences were also analyzed although this was not part of the original design of the study. The unit of analysis here was data from each individual student. Each analysis is presented and described in turn.

Were there Differences by Prior Coursework or Gender before the Tonga Learning Activity with Google Earth?

We first addressed if there were any differences on the pre-test by prior coursework and by gender; in other words, whether there was a difference on students' knowledge going into the pre-test either by prior coursework in geology and/or geography, or by gender. A univariate analysis of variance was computed for each of these analyses. The difference between the total scores on the pre-test was not statistically significant when comparing those with prior coursework to those with no prior coursework ($F = 3.052$, $p = 0.051$). Secondly, there was no statistically significant difference on the total pre-test score when comparing the males and females ($F = 1.831$; $p = 0.179$; see footnote 3). See Table 17 for means and standard deviations for each of these analyses.

Were Differences in Overall Pre-Post Comparisons Found for the Tonga Activity?

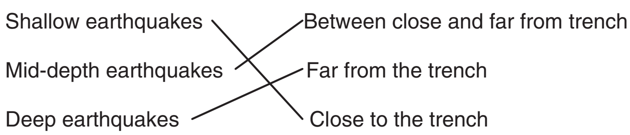
Next we addressed if there were differences in overall post-test scores compared to pre-test scores collapsing over prior

TABLE 15. QUESTION 4 AND ITS CODING SCHEME FOR THE TONGA ACTIVITY

Q4 On which side of the trench do we expect to see earthquakes on, the down-going plate (on the east side of the trench in this case) or the over-riding plate (on the west side of the trench in this case)?
over-riding plate or west side (1 pt)

TABLE 16. QUESTION 5 AND ITS CODING SCHEME (1 POINT FOR EACH PROPER MATCH) FOR THE TONGA ACTIVITY

Q5 Match the depth of the earthquakes based on their distance from the trench. Put one distance for each depth.



coursework and gender. A paired t-test was computed. The difference in overall pre-test score and overall post-test score was statistically significant, [t(136) = 6.591, p = 0.000; $\bar{X}$pre = 0.82, SD = 0.35; $\bar{X}$ post = 1.09, SD = 0.38]; this result demonstrates that on average, students had higher scores on the post-test than on the pre-test (see Table 18 and Figure 4).

Were Post-Test Differences by Type of Prior Coursework Found for the Tonga Activity?

We addressed whether there were differences between the pre- and post-test scores when comparing those with prior coursework in geology or geography to those with no relevant prior coursework. To do this, we conducted a univariate analysis of variance with the total post-test as the dependent variable and type of prior coursework as the independent variable. Pre-test was used as a covariate. The difference in post-test score by type of prior coursework was not statistically significant (F = 0.692; p = 0.502). Thus, both students with prior coursework and those without prior coursework learned approximately the same amount of content knowledge from the Tonga lab, as measured by the post-test, when holding the pre-test scores constant. The means and standard deviations can be seen in Table 19.

Were Post-Test Differences by Gender Found for the Tonga Activity?

In order to address whether there were differences when comparing males and females on their post-test scores for the Tonga activity, a univariate analysis of variance was conducted with the total post-test as the dependent variable and gender as the independent variable. Pre-test was used as a covariate. The difference in post-test score by gender was not significant (F = 0.545; p = 0.462). Thus, both males and females learned approximately the same amount of content knowledge, as measured by the post-test. The means and standard deviations can be seen in Table 20.

WereThere any Differences on the Lab Scores for the Tonga Activity When Comparing Groups by Prior Coursework or by Gender?

Next, we addressed the differences on the lab activity scores both by prior coursework and by gender; in other words, whether

TABLE 17. AVERAGE SCORES ON PRE-TEST BY TOTAL, GENDER, AND PRIOR COURSEWORK FOR THE TONGA ACTIVITY

	Female	Male	Geology and/or geography	No geology or geography
Mean pre-test score	0.88	0.80	0.86	0.85
Standard deviation	0.36	0.31	0.25	0.36
Mean post-test score	1.13	1.07	1.03	1.12
Standard deviation	0.37	0.39	0.39	0.35

TABLE 18. OVERALL SCORES FOR PRE- AND POST-TEST FOR THE TONGA ACTIVITY

	Pre-test	Post-test	t (df)	p
Overall score	0.82	1.09	6.591 (136)	0.000*
Standard deviation	0.35	0.38		

*Significant at the p < 0.001 level.

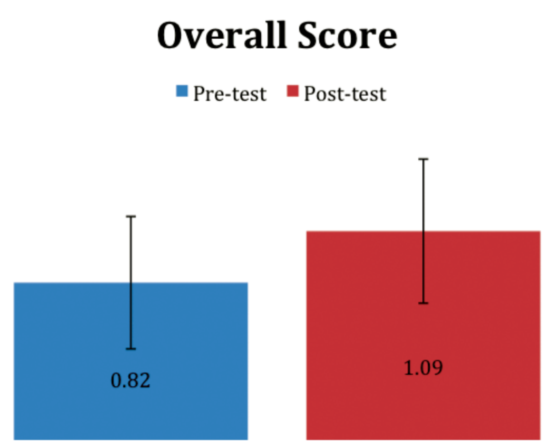


Figure 4. Overall scores on both pre-test and post-test for the Tonga activity.

TABLE 19. AVERAGE SCORES ON PRE-TEST AND POST-TEST FOR THE TONGA ACTIVITY BY TYPE OF PRIOR COURSEWORK

	Geology and/or geography	Non-geology and/or geography
Mean pre-test score	0.86	0.85
Standard deviation	0.25	0.36
Mean post-test score	1.03	1.12
Standard deviation	0.39	0.35

there was a difference on students' performance in the lab activity by prior coursework in geology and/or geography, or by gender. A univariate analysis of variance was computed for each of these analyses. The difference between the total scores on the lab activity was not statistically significant when comparing those with prior coursework to those with no prior coursework ($F = 0.738$, $p = 0.480$); however, the difference on the total scores on the lab activity was statistically significant when comparing males and females ($F = 8.463$, $p = 0.004$). This result demonstrates that on average, males outperformed females on the lab activity (see Table 21 and Fig. 5).

Correlations between Pre-Test, Lab, and Post-Test Scores

In order to establish whether there was a relationship between each of the three scores, a Pearson correlation analysis was conducted using the pre-test, post-test, and lab scores. A statistically significant correlation was found between the pre-test and lab scores ($r = 0.384$, $p = 0.000$, [two-tailed]), indicating a moderate, positive relationship between pre-test and lab scores. Pearson correlation values can be seen in Table 22. These results are depicted in Figure 6.

DISCUSSION

Summary of Goals and Approach

In this research and development effort, we report on two studies that examined the efficacy for learning with Google Earth lab activities. This involved examining students' prior knowledge, their knowledge acquired during the lab activity, and their post-test learning gains, thereby examining both the processes (answers to the lab exercises) and products of learning (post-test compared to pre-test); an approach that is important since it has the potential to inform instruction in the geosciences (Libarkin and Anderson, 2005).

Our goal in these studies was to compare learning during the lab activity, as well as the resulting learning gains by comparing pre- and post-test scores for those with prior geology and/or geography coursework to those with no such prior coursework. This research question is important in terms of addressing the efficacy of Google Earth as a learning tool for both majors and non-majors since Google Earth is potentially important to scientific literacy on a broad scale (AAAS, 1993; National Research Council, 1996). Our findings suggest that Google Earth can be an effective learning tool for non-majors, and thus, it also has potential efficacy for scientific literacy on a broad scale.

We also compared learning gains of males and females, although it was not part of the original research design. That is, since there have been a plethora of studies that have reported gender differences in science (Halpern and LaMay, 2000; Linn and Petersen, 1985; Maccoby and Jacklin, 1974; McGee, 1979), and in geoscience in particular (Kali and Orion, 1996; Downs and Liben, 1991; Piburn et al., 2005; Schofield and Kirby, 1994), it was a research question that we could address in the present studies. Similar to the issues around the type of prior knowledge students have coming into our studies, addressing whether there are differential learning gains yielded by males versus females allows us to address the efficacy of Google Earth as a teaching tool for both genders. If gender differences were to be borne out, we as a community of educators would need to begin to think about how to scaffold different learners to accommodate these differences.

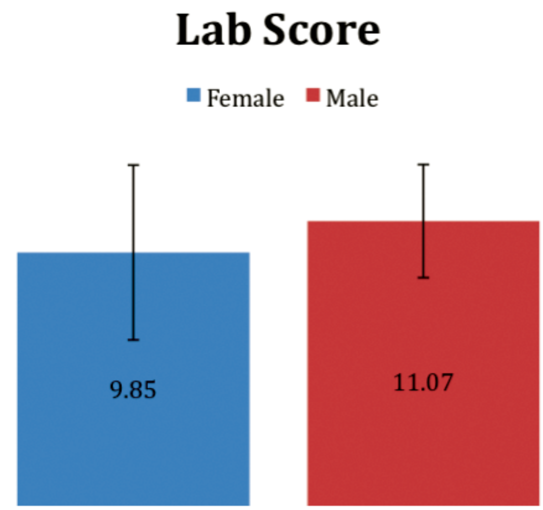


Figure 5. Total lab score by gender for the Tonga activity.

TABLE 20. TONGA ACTIVITY RESULTS OF AVERAGE SCORES ON PRE-TEST AND POST-TEST BY GENDER

	Female	Male
Mean pre-test score	0.88	0.80
Standard deviation	0.36	0.31
Mean post-test score	1.13	1.07
Standard deviation	0.37	0.39

TABLE 21. AVERAGE SCORES ON THE TONGA LAB ACTIVITY BY GENDER

	Female	Male	p
Lab score	9.85	11.07	0.004*
Standard deviation	3.40	2.20	

*Significant at the p <0.005 level.

TABLE 22. PEARSON CORRELATION VALUES BETWEEN PRE-TEST, POST-TEST, AND LAB SCORES FOR THE TONGA ACTIVITY

	Pre-test	Post-test	Lab
Pre-test	1	0.123	0.384*
Post-test	0.123	1	0.153
Lab	0.384*	0.153	1

*Significant at the 0.01 level of alpha.

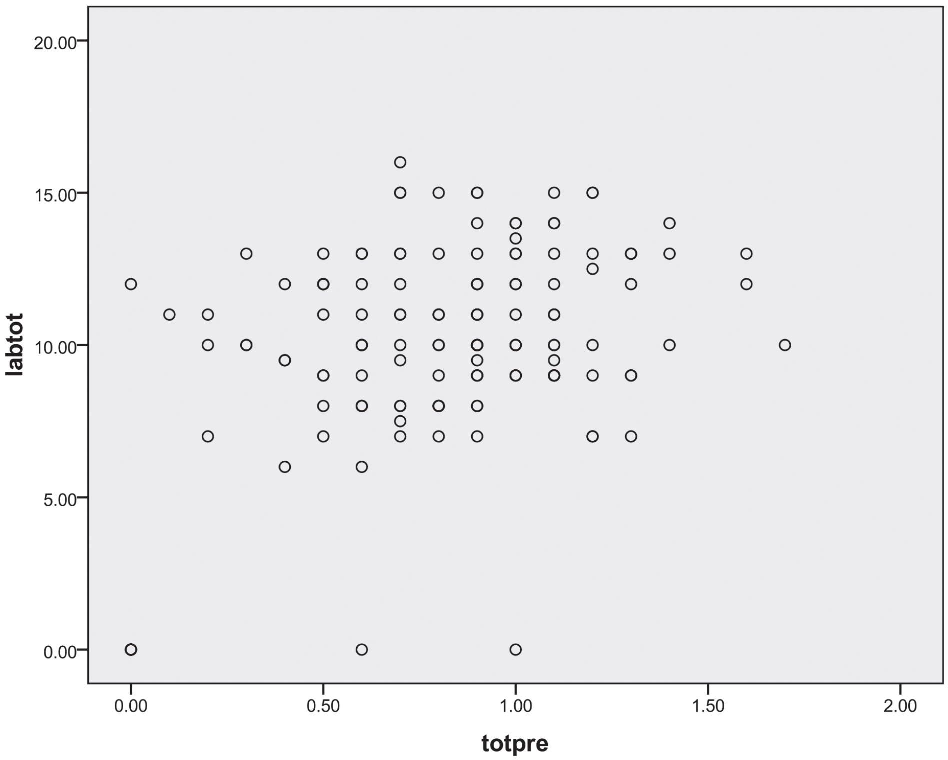


Figure 6. Scatterplot of correlation between total lab scores and total pre-test scores for the Tonga activity.

Overview of Findings Regarding Prior Coursework

In the first study, we used an activity developed in Google Earth by Declan De Paor and his group (De Paor and Whitmeyer, 2008, NSF-CLLI #0837040). The goal of this activity was to deepen students' understanding of the geography and geology of Iceland. The concepts and knowledge targeted here were: specifying Iceland's relationship geographically with respect to the Arctic Circle, using the time slider to observe the horizon, asking students what they would expect to see here at the Winter Solstice, observing geological features (e.g., rock types), observing the formation of the Mid-Atlantic Ridge by using a time slider, noting how the Mid-Atlantic Ridge is displaced across the Gibbs Fracture Zone, and observing the plate-plume interaction under Iceland. In the second study, we used an activity, also developed by Declan De Paor and his group (De Paor and Whitmeyer, 2008), which was more difficult than the first activity in terms of the geoscience content it targeted. Specifically, the activity consisted of: locating the Tonga region with respect to the Tropic of Capricorn; viewing and manipulating virtual block diagrams to observe animations of subduction; island arc formation and trench migration; and answering questions about the relative location of volcanoes, earthquakes, plate movement, trench formation, plate movement, and trench rollback.

Our results for the two studies were highly similar and thus will be summarized together, except for one measure for which significant differences exist.

Our data for both studies showed that there were overall gains in learning when comparing all students' scores—that is, collapsing over type of prior coursework and gender, all students, on average, had higher post-test scores compared to their pre-test scores for both the Iceland activity as well as the Tonga activity. Since there were no group differences on the pre-test by either type of prior coursework or by gender for either the Iceland or the Tonga activities, we can attribute our post-test gains as being due to the Google Earth labs for Iceland and Tonga, respectively.

When analyzing post-test gains by type of prior coursework (geology and/or geography versus no prior coursework in either of these areas), we found that there were no significant differences, on average, for those with prior coursework in geology or geography when compared to those with no prior coursework in these areas for either the Iceland lab or the Tonga lab. This suggests that the two Google Earth labs were effective as learning activities, regardless of the type of prior coursework.

This finding is important because prior studies that have used traditional methods of geoscience instruction often do not yield large learning gains (Libarkin and Anderson, 2005; Hall-Wallace and McAuliffe, 2002). Furthermore, our findings are commensurate with prior research that showed that rich dynamic visualizations such as GIS and Google Earth are successful at remediating students' misconceptions about 3-D geoscience phenomena such as ocean ridges and tsunamis (Hall-Wallace and McAuliffe, 2002); ocean ridges were targeted in our activities in both the Iceland and Tonga activity. Findings from our studies suggest that Google Earth appears to provide a means of deep learning for students that *does not* hinge on prior coursework, thus our data suggest that Google Earth is a useful tool for undergraduate education, regardless of prior relevant coursework. Thus, in terms of promoting scientific literacy, Google Earth may also be very effective with the general public, but additional research would need to be conducted since students in this study were self-selected by virtue of signing up for the geoscience course from which this subject population was drawn, and thus may have been favorably predisposed to this content, etc.

Overview of Findings Regarding Gender

When analyzing our post-test gains for each Google Earth activity by gender, we see that males and females gained, on average, about the same amount of content from the activities. Furthermore, because there were no differences due to gender on the pre-tests scores for either activity (see footnote 3), our data suggests that this effect is not due to differences that the students had before the activity. One gender difference, favoring males, was found for the Tonga lab on the items that were answered as students worked through the lab activity. Specifically, on the Tonga lab, the more difficult of the two labs, males outperformed females in terms of the number of correct items they answered. However, since there were no significant differences by gender yielded on the post-test for the Tonga activity, the differences favoring males on the lab items were not robust enough to be reflected in the males' post-test understanding.

These findings are important since many studies have shown that males tend to outperform females on spatially oriented tasks (cf. Halpern and LaMay, 2000; Linn and Petersen, 1985; Maccoby and Jacklin, 1974; McGee, 1979). In geoscience in particular, few studies regarding gender effects have been conducted (Kali and Orion, 1996; Downs and Liben, 1991; Piburn et al., 2002; Schofield and Kirby, 1994) although researchers have noted a need to address the relationship of spatial skills to specific sciences, rather than as science in the aggregate (Lau and Roeser, 2002). In terms of such studies, Dabbs et al. (1998) found that basic spatial skills contribute to geographic knowledge and that men tended to excel at mental rotation, whereas women tended to excel at object location. Black (2005) found a relationship between specific types of spatial skills, namely mental rotation and earth science misconceptions (Black, 2005). Black hypothesized that mental rotation is required to visualize the position of objects from varying vantage points, and further that this is the type of mental rotation needed for understanding both seasonal change and phases of the moon, two areas in which significant misconceptions have been found. In terms of the present study, we found only one gender difference of the several measures taken, and as previously stated, this difference favoring males was not robust enough to be maintained, as evidenced by the lack of differences due to gender on the post-test. Thus, from our data, it appears that Google Earth does not offer a differential bias for one gender over another. Furthermore, since Google Earth has features that permit students to manipulate the tilt of Earth in order to view it from different vantage points, Google Earth may have provided a means to support learners on this difficult task. The study by Black (2005) suggests that this is a strong possibility.

All told, our data suggest that Google Earth is a useful tool for learners regardless of level of prior coursework in geology or geography, and regardless of gender. As such, it has the potential to be used to address scientific literacy on a broad scale.

Scaffolding Learning

As previously stated, all complex learning should be accompanied by orienting tasks or scaffolding in order to support students' learning processes. Students, unlike experts, typically do not know what is salient within rich information sources (Lowe, 1993) such as Google Earth, and thus, if unscaffolded (i.e., unguided) they might not acquire the targeted information as intended. This is particularly true in domains in which the medium of information is visual-spatial in nature in which all information is presented to the learner simultaneously. This is in direct contrast to textual information sources in which the knowledge acquisition processes are guided by the structure of the text (Larkin and Simon, 1987; Gobert, 2005a). In prior work, Bodzin and Cirucci (2009) noted that resources such as Google Earth, when used in conjunction with appropriately designed instructional materials, show much potential in promoting students' spatial thinking. Our data, which yielded learning gains, also support this.

In the present study, a great deal of effort was taken to ensure that the lab exercises both oriented and scaffolded the students in order to deepen their learning. It is doubtful that learning gains would have been found for both those with and without prior coursework if the learning activities had not been well designed, although the activity with and without its scaffolding and orienting was not tested as part of this study. Thus, for those using Google Earth as a pedagogical tool at any level of education (K–graduate school), it is important that care is taken to guide students' knowledge acquisition processes in order to deepen their learning. Scaffolding is particularly important when novices are learning with visual information sources (Lowe, 1993). The materials developed by De Paor, Steve Whitmeyer, and their colleagues (NSF-CCLI #0837040, De Paor and Whitmeyer, 2008; NSF-GEO #1034643, De Paor, and Whitmeyer, 2010; and NSF-DUE #1022755, De Paor et al., 2010) that were used in the present research provide a good example for how such scaffolding is accomplished.

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