2009

The InVEST volcanic concept survey: Assessment of conceptual knowledge about volcanoes among undergraduates in entry-level geoscience courses

Thomas Lyle Parham
Iowa State University

The InVEST volcanic concept survey: Assessment of conceptual knowledge about volcanoes among undergraduates in entry-level geoscience courses

by

Thomas L. Parham Jr.

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Geology

Program of Study Committee:
Cinzia Cervato, Major Professor
William A. Gallus Jr.
Michael Larsen
Thomas Greenbowe

Iowa State University

Ames, Iowa

2009

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A growing body of geoscience education research suggests that many students in the American K-12 system do not fully understand key geoscience concepts. Moreover, early misunderstandings appear to persist even at the introductory undergraduate level. This thesis focuses on exploring the understanding of volcanic systems among American undergraduates via a new assessment instrument, the Volcanic Concept Survey (VCS), which has collected over 600 student responses from a diverse sample of undergraduates across the country. Initial results show that student understanding of volcanic processes is rather limited. Specifically, students tended to possess only basic content knowledge, while concepts requiring the use of higher thinking skills were not well understood. Further explorations of demographic data for the student population reveal that, among other factors, the students' source of knowledge about volcanoes can significantly impact the quality of their understanding. Students who learned from non-traditional film and media sources did not score as highly on the VCS instrument as their peers. The severity of this problem underscores a need for change. Thus, to promote deep and robust learning, new strategies may be necessary when teaching volcanology in the modern introductory geoscience classroom. While simulations will never fully rival the experience of fieldwork, VCS results are being applied to optimize the pedagogical value of an upcoming highly interactive and visually stimulating Virtual Volcano teaching tool.

CHAPTER 1: GENERAL INTRODUCTION

Introduction

Knowing the nature of student thinking is paramount to the development of effective pedagogy. Moreover, a clear understanding of what students know and how they learn can inform the development of new teaching tools and techniques. Many scientific disciplines have been rigorously exploring student knowledge and researching student preconceptions for decades. Physics, in particular, benefits from a long tradition of preconception research at both the K-12 and undergraduate levels. Chemistry also has a strong culture of discipline-specific pedagogical research. In recent years, leaders in geoscience education have been working to close the gap between Earth science and the other science disciplines. This thesis represents a contribution to the much larger goal of building a broad, robust, and up-to-date research base in geoscience education.

A broad and robust scholarship of geoscience education must explore student understanding of all key geoscience concepts. Student understandings of some key concepts, such as climate change or deep time, have been relatively well explored by existing work in the geoscience education literature. Preconception studies have largely been focused in these "hot topic" areas, but some have also explored how students conceptualize Earth structures, mountain building processes, or geological hazards such as earthquakes. This thesis addresses the fact that, to date, studies specifically assessing student understanding of volcanic systems have been lacking. Moreover, despite the fact that many geoscience educators teach large-enrollment entry-level undergraduate courses, the work that has been done on volcanoes has not surveyed the American undergraduate population.

Most research into how students learn key geoscience concepts has focused on issues related to mental scaling and spatial perception, or the influence of non-scientific personal belief systems. Despite the ever-growing presence of new media in the daily lives of college students, relatively few studies have specifically and rigorously explored the effects of learning scientific content from the popular media and mainstream cinema. If the geoscience education research base is to remain current, then it must contain studies on the effects of learning from these new media sources and explore cutting-edge learning technologies.

This thesis presents a robust new instrument for assessing student understanding about volcanoes, the Volcanic Concept Survey (VCS), and discusses results from preliminary testing among a large population of American undergraduates. The primary objective of this work was to discern what misconceptions and/or preconceptions students had about volcanoes and plate tectonics at the undergraduate level. Secondly, this thesis specifically explores the effect of non-traditional sources of knowledge on student understanding of volcanic systems. Finally, and perhaps most importantly, suggestions are made throughout for improving the quality of instruction on volcanology.

The data and discussions presented in this thesis also represent the critical groundwork necessary for designing a new, interactive Virtual Volcano teaching tool as part of the Interactive Virtual Earth Science Teaching (InVEST) project. The Virtual Tornado[1] simulation is being used as a proof-of-concept model, and Virtual Volcano is being designed to specifically target student preconceptions about volcanoes. This simulation could be readily incorporated into K-12 and undergraduate Earth science curricula.

---

[1] http://www.vrac.iastate.edu/research/sites/tornado/

Thesis Organization

The remainder of this thesis is organized as follows: Chapter 2 presents the development of the Volcanic Concept Survey (VCS) instrument and discusses initial results. This chapter is presented in the form of a paper, entitled "The InVEST Volcanic Concept Survey: Exploring Student Understanding about Volcanoes", which I submitted in March 2009, along with Dr. Cinzia Cervato, Dr. William Gallus, and several other InVEST project collaborators, to the Journal of Geoscience Education. This paper is currently under review for publication.

Chapter 3 is a paper, entitled "Is Hollywood to Blame for Students' Poor Understanding of Volcanoes and Plate Tectonics?", which is currently in preparation for submission to the Journal of College Science Teaching. This paper specifically explores student "source of knowledge" (SoK) and the impact of learning about volcanoes from non-traditional sources. Other demographic predictors of high score on the VCS are also addressed in the discussion section of this paper.

Chapter 4 provides a general conclusion to this thesis, with special emphasis on the potential for future research and application of results to ongoing development of an interactive Virtual Volcano teaching tool.

A copy of the Volcanic Concept Survey, which is also available online as part of the CHRONOS portal[2], is provided in the Appendix. This represents the current version of the instrument, which may be used for student assessment or employed in future studies.

[2] http://www.chronos.org/resources/DemoVolcanoTemplate.pdf

CHAPTER 2. THE INVEST VOLCANIC CONCEPT SURVEY: EXPLORING STUDENT UNDERSTANDING ABOUT VOLCANOES

A paper submitted to the Journal of Geoscience Education, March 2009.

Thomas L Parham Jr.[3], Cinzia Cervato[2], William A. Gallus Jr.[2], Michael Larsen[4], Jon Hobbs[3], Pete Stelling[5], Thomas Greenbowe[6], Tanya Gupta[5], John Knox[7], and Thomas Gill[8]

Abstract

Results from the Interactive Volcanic Concept Survey (VCS) indicated that many undergraduates do not fully understand volcanic systems and plate tectonics. During the 2006 academic year, a ten-item conceptual survey was distributed to undergraduate students enrolled in Earth science courses at five U.S. colleges and universities. A trained team of graders scored 672 completed surveys, coding responses to each item with a score, out of 3, based on accuracy and comprehensiveness. Questions requiring only basic content knowledge (e.g., terminology, volcano topology) received more high scoring responses than questions requiring higher thinking and deeper conceptual connections (association with plate tectonics, prediction of hazards and impacts on the environment). The mechanics of eruptions also appeared to be poorly understood. Special attention was paid to students' alternate conceptions about where volcanoes are likely to form. Male students, students highly interested in science, and students who lived in a volcanically active area received significantly higher total scores than other student groups. Science, technology, engineering,

[3] Department of Geological & Atmospheric Sciences, Iowa State University
[4] Department of Statistics, Iowa State University
[5] Department of Geology, Western Washington University
[6] Department of Chemistry, Iowa State University
[7] Department of Geography, University of Georgia
[8] Department of Geological Sciences, University of Texas at El Paso

and mathematics (STEM) majors also performed significantly better than non-STEM majors. Understanding the nature of student comprehension and misconception may be useful for geoscience educators seeking to address student preconceptions and promote conceptual change.

Introduction

Multiple studies show that many incoming college students have a weaker grasp of key geoscience concepts than expected. The fundamental theory of Plate Tectonics and several associated phenomena are included as national science curriculum standards as early as in grade five (National Research Council, 1996). Yet, recent studies (e.g., Libarkin and Anderson, 2005; Marques and Thompson, 1997) demonstrate that significant alternate conceptions related to plate tectonics persisted even at the undergraduate level. Students also have a poor understanding of tectonically driven phenomena, such as earthquakes (Barrow and Haskins, 1996) and are confused about mountain building processes (Chang and Barufaldi, 1999; Muthukrishna et al. 1993). Studies of student preconceptions about volcanoes have been conducted on Italian high-school age children (Bezzi and Happs, 1994), but U.S. undergraduates' ideas about volcanoes remain largely unexplored.

Studies of student preconceptions are critical to the advancement of geoscience education, because knowing the nature of students' prior knowledge helps instructors to specifically confront inaccurate ideas with their scientific alternatives (Libarkin and Kurdziel, 2001). Education research has long suggested that this approach is an effective way to achieve conceptual change (e.g., Driver and Odham, 1986). One way to assess students' prior knowledge is the administration of a concept inventory or conceptual knowledge survey. The physics education literature has explored student preconceptions since the 1980s (Halloun and Hestenes, 1985), eventually leading to the development of a famous instrument for assessing student knowledge, the Force Concept Inventory (Hestenes et al., 1992). Similarly, the Geoscience Concept Inventory (Libarkin and Anderson, 2006) represents a robust and highly successful instrument that addresses a broad variety of key geoscience concepts. Other geoscience concept test and questionnaire studies have taken a similarly broad approach (e.g., McConnell et al., 2006; Cervato et al., 2007), while a few have focused specifically on a subject of particular concern, such as geologic time (Parham et al., 2005; Libarkin et al., 2007).

As part of a broad long-term effort to explore student understanding and develop new teaching tools, the Interactive Virtual Earth Science Teaching (InVEST) project team created the Volcanic Concept Survey (VCS), a topic-centered concept test which was designed to explore undergraduate preconceptions about volcanoes. Results from the VCS have significant curricular and pedagogical implications for introductory geoscience instruction. Moreover, the methodologies used to analyze students' open-ended responses on the VCS may prove useful for the development of other instruments. Here we describe the design, development, and dissemination of the VCS and report on the demographics of the survey population. We explain in detail the scoring procedure and a preliminary study of grader reliability. Finally, we present qualitative and limited quantitative results of the survey, including areas of best and least understanding, together with a discussion of how these data may inform geoscience educators seeking to improve their quality of instruction. These findings may be particularly useful to educators who wish to promote conceptual change by directly addressing student preconceptions.

Survey Instrument

The InVEST VCS development team consisted of faculty members in geology, meteorology, and chemical education. A volcanologist and experts in science education were consulted on issues of content validity and two statisticians provided expertise on survey design. Moreover, a graduate student in chemical education and a senior-level undergraduate in geoscience education helped ensure that the questions were phrased intelligibly for an undergraduate population.

The final survey consisted of two primary components: a free-response survey and an attached demographic questionnaire. The free-response section consisted of ten open-ended questions on a variety of volcanic concepts. These are available online[9] and are shown in Table 1. Many concept inventories use a multiple-choice format or employ Likert scales. However, we chose to leave questions open-ended to give students the opportunity to demonstrate the full extent of their thinking and establish connections between volcanic concepts. For example, question four of the InVEST instrument (*Think about the location of volcanoes on land around the world. Is there a pattern to their location, and if so, what might control that pattern?*) attempts to further explore the topics addressed by question 13 from version 2.1.1 of the GCI (Figure 1; Libarkin and Anderson, 2009). Questions on the final version of the VCS were carefully chosen to span a variety of concepts related to volcanism and assess students' thinking across many levels of Bloom's Taxonomy (Figure 3; Bloom, 1956).

---

[9] http://www.chronos.org/resources/DemoVolcanoTemplate.pdf

An additional multiple-choice question assessed source(s) of student knowledge regarding volcanoes (i.e. traditional coursework, movies, documentaries etc). Specially allotted free space at the end of the instrument allowed students to ask questions or share information about volcanoes that they felt had not been addressed. The attached demographic questionnaire collected data on student background including gender, age, major, and learning preferences. This was designed to aid in the statistical analysis of survey results and support future in-depth research on the influence of learning styles and demographic factors on students' conceptual frameworks.

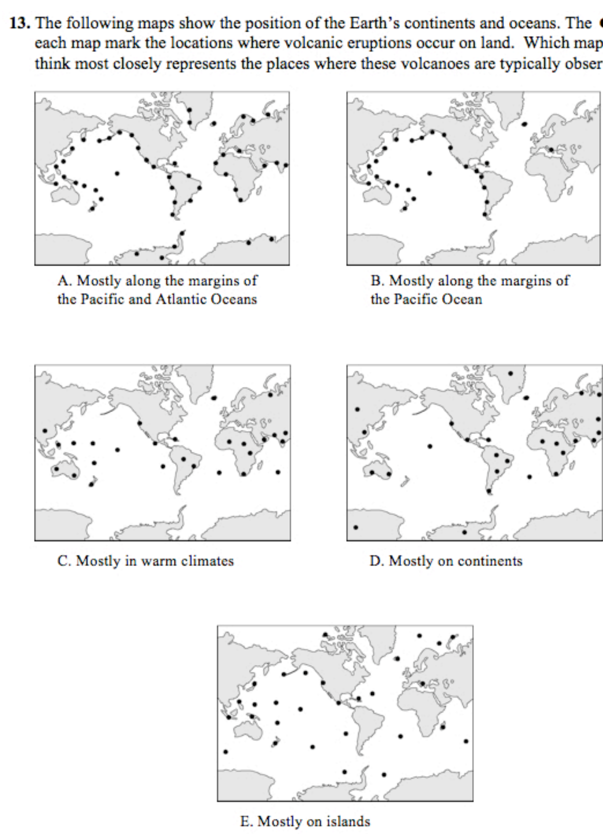

Figure 2.1: Sample GCI question exploring volcanic pattern. Reproduced from online GCI v2.1.1 (Libarkin and Anderson, 2009 - https://www.msu.edu/~libarkin/gci.html).

#	Question	Idealized Student Response
1	Are all volcanoes similarly shaped? If not, how many distinct shapes can be seen? (Feel free to illustrate your ideas below) [Space Provided]	Some volcanoes (shield) are wide, broad and shallow-sloped. Some volcanoes (composite or stratovolcanoes) are steep-sided and rise to a peak, like an overgrown anthill. Some volcanoes (calderas) are partly destroyed, and look like giant holes in the ground.
2	What is the difference between lava and magma?	Magma is the combination of liquid rock, crystals, and gas below the surface. Lava is the same thing as magma but it is on top of the surface (exposed to air and/or surface water).
3	Describe the composition of a typical volcano. In other words, if you could cut a volcano in half, what would you see on the inside?	Many layers inside, often alternating between lava flows and ash (this is more likely in a stratovolcano). The layers slope away from the center of the volcano. There will also be many dikes (intrusions/veins/filled cracks) oriented more or less vertically, especially toward the center of the volcano (this could be called the "throat" or more correctly called the "conduit).
4	Think about the location of volcanoes on land around the world. Is there a pattern to their location, and if so, what might control that pattern?	Most volcanoes occur in linear belts and are often near the coast. Many underwater volcanoes occur in linear belts that run along the middle of the ocean floor. These volcanoes are controlled by the movement of tectonic plates, either running into each other (subduction) or spreading apart (spreading center or mid-ocean ridge). Some "hot spot" volcanoes occur somewhat randomly, and these are caused by thin, pencil-shaped plumes of hot material in the Earth's interior (mantle plumes).
5	Why does a volcano erupt?	Bubbles of volcanic gas become highly pressurized, and if the pressure of the bubbles within the magma exceeds the pressure of the rocks surrounding the magma, the rocks break and release the over-pressurized bubbly fluid.
6	What controls how explosive a volcanic eruption will be?	How many bubbles there are (which depends on how much water is present in the magma), How thick/sticky (viscous) the magma is (this depends on how much silica is present in the magma and how hot the magma is.
7	How does water in a volcanic system affect how explosive a volcanic eruption will be?	If there is more water vapor in a magma, there will be more bubbles and each bubble will have more water in it, creating higher pressures. So, more water = more explosive eruptions
8	Draw a picture of an erupting volcano and identify as many features as you can.	Should show at least the following: lava flow, pyrocalstic flow, and ashfall/ ash cloud
9	Volcanic eruptions can create natural hazards beyond the eruption of lava and ash. In the left column, list hazards caused by erupted material. In the right column, identify hazards caused by the interaction of these materials with their surrounding environment. [Two columns provided]	Eruption Material Hazards: Ash fall (including big rocks), Pyroclastic flow, Lava flow, Volcanic gases, etc Envrionmental Hazards: Lahar (mud flow), Lightning, Floods (melting of glacier, joekulhaup), Tsunami, etc
10	As specifically as possible, describe how a volcano might affect the following people or groups of people in the region: A. A farmer living at the base of the volcano: B. A tourist lodge along a stream flowing down from the volcano: C. A pilot of a 747 flying through an area above the volcano: D. A group of skiers on the side of the volcano:	A.) Plants would smother under ash; later crops would thrive in rich soil. Risk for pyroclastic flow, lahar if near a river, too much ash fall crushing his/her home. B.) Proximity to stream puts them at great risk for lahar, also pyroclastic flow, perhaps floods (though these are rare). Fish population could be affected by ash in water, or by decrease in pH due to acidic gases in water. C.) Ash can reduce visibility, scratch windows, stall jet engines, scour wings and reduce lift. D.) Gases released (especially CO2) may accumulate in low pockets causing asphyxiation, or can burn if super-heated; melting of snow can create floods and/or lahars.

Table 2.1: Questions used in the VCS, each with an example of idealized student response. For each item, if students approximated these responses, graders were to award the maximum score (3).

Study Population

During fall 2006 and spring 2007 semesters, five participating colleges and universities administered the VCS within the first week of class, prior to instruction about volcanoes and plate tectonics. Some instructors chose to offer extra credit for participating. The institutional review boards of all institutions approved the instrument during summer 2006 and allowed the use of student responses for research. A total of 672 students [Iowa State University (n = 432), University of Texas - El Paso (n = 103), University of Georgia (n = 72), Western Washington University (n = 27), and Fort Valley State University (n = 38)] signed a consent form allowing their responses to be used for research purposes. Allotted time to complete the entire instrument (demographics and questionnaire) varied between twenty to thirty minutes.

The selection of participating school was guided by our interest in covering a broad and diverse student population and to include students from predominantly undergraduate institutions as well as research universities. The large proportion of students from Iowa State University (ISU), the project's home institution, is primarily due to the high enrollment levels (500+ students) in introductory physical geology each semester. Smaller samples collected from other institutions reflect both class size at the respective school and, to a lesser extent, willingness of students to participate in the study. Overall, the survey population included 357 (53.1%) female and 315 (46.9%) male students. Students who identified themselves as a racial minority accounted for 30.4% of the total population. Hispanic and Latino/a students accounted for half of the minority sub-group. The Fort Valley State students were divided between two courses: one for science majors and one for non-science majors. Other courses were general education and "service" courses. Overall, sixty-four percent of the students in the total population were undeclared or non-science majors.

Evaluation

Due to the open-ended nature of the questions, each survey needed to be reviewed and scored to allow any quantitative analysis. Moreover, the large number of responses necessitated delegation of scoring responsibilities among a group of graders, which consisted of three undergraduates, one graduate student, and three faculty members at ISU. All graders attended a training session with members of the development team, during which the idealized response for each question (Table 1) was shared and discussed. Then, each grader independently coded the same random selection of twenty surveys, assigning individual item responses a score between 0 and 3. During this phase, graders had the opportunity to discuss questions that arose during their reading of the responses to the test surveys but each grader completed the scoring independently. Non-informative responses ("I don't care", etc), or a failure to convey any measure of understanding received a score of zero. Often, zero-level responses consisted of a single word, or were entirely blank. A score of 1 corresponded to a minimal level of understanding, while a score of 2 indicated further developed and/or accurate responses. Conceptual mastery, coded as a maximum score of 3, was identified by close approximation of the idealized response (Table 1). Table 2 provides examples of high-scoring, moderate, and low-level responses to two VCS questions. Similar score coding approaches have been used to categorize and statistically analyze open-ended responses on highly vetted assessments of student knowledge, including the Trends in International

Mathematics and Science Study (TIMSS) (Gonzales et al., 2008) and National Assessment of Educational Progress (NAEP) (National Assessment Governing Board, 2008).

To test for consistency and agreement among graders, and to test whether grader training had been effective, we performed statistical analysis on the scores of the twenty sample surveys utilizing intraclass correlations (ICC) with random grader effects (Shrout and Fleiss, 1979). A high ICC value implies that scores assigned by all graders to a given response were highly correlated. Thus, if ICC value is high (> 0.5), a response that was scored as a 2 by one grader was likely to be a given a 2 by any other grader. The higher the ICC value, the more agreement existed among all graders.

Question	**Strong Response** (Score Level 3)	**Moderate** (Score Level 2)	**Weak Response** (Score Level 1)
#3: Describe the composition of a typical volcano. In other words, if you could cut a volcano in half, what would you see on the inside?	"Layers of rock with lots of cracks on the sides and a deep chamber with magma coming up through the center."	"Rocks on the outside, magma inside" "Rocky cone and magma pipe inside"	"Magma at the bottom" "Lava tunnel inside" "Layers of magma"
#5: Why does a volcano erupt?	"Hot gases build up under pressure until magma breaks through the rock and escapes …"	"Lava is squeezed by pressure" "Too much heat and pressure inside"	"Magma overflows" "A build up inside as lava rises from the center of the earth" "Magma gets hot and expands"

Table 2.2: Examples of student responses across score levels. Higher scores represent closer approximation of the idealized response (Table 1). For example, in the case of question 5, high-scoring responses discussed the effects of gas pressure on magma, while low-scoring responses were likely to neglect the role of volcanic gases and/or propose entirely different driving mechanisms, many of which indicate non-scientific preconceptions about Earth's interior.

The results of this consistency test (Table 2) indicate that grader agreement was quite high for both total survey score and average item score. More importantly, grader agreement was strong for all but one of the items on the survey. Question 10 (Table 1) had less than ideal grader agreement on parts A, B, and D. However, when taken as a whole, grader agreement on question 10 (10Tot, Table 3) was much stronger. Thus, while graders occasionally scored individual parts of question 10 differently, the total number of points assigned for the entire question was consistent.

To further explore the possibility of grader effects, we constructed side-by-side boxplots for all graders with respect to total score distribution (Figure 2). Only minor variations in location and variability were present, so no statistical corrections for grader effects were applied in further analyses. Upon conclusion of reliability testing, each grader scored a random subset of completed surveys, and compiled score data.

Item	ICC	Item	ICC
Q1	0.700	Q9	0.596
Q2	0.818	Q10A	0.394
Q3	0.676	Q10B	0.422
Q4	0.665	Q10C	0.542
Q5	0.708	Q10D	0.213
Q6	0.669	Q10	0.526
Q7	0.665	Total	0.857
Q8	0.603	Average	0.857

Table 2.3: Intraclass correlations (ICC) for each item, as well as complete survey (Total), and average scores. Higher values indicate greater reliability. Parts of question ten (Table 1 #10a-d) were examined individually (10A, 10B, etc), but also factored into a composite question ten score (10Tot).

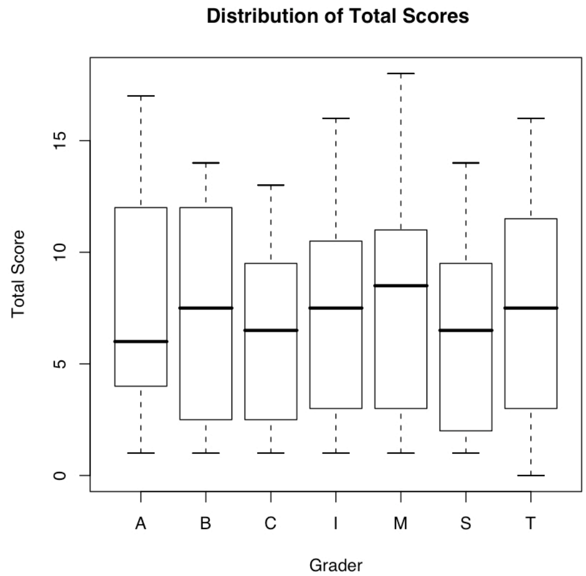

Figure 2.2: Boxplots for total score by grader. Each single letter ID represents a unique grader.

Results

Survey results suggest that student understanding of volcanic processes was rather limited. The average total score on the instrument was twenty-five out of a possible thirty-nine points. However, for the purpose of exploring students' understanding of specific concepts, individual question scores are more revealing. Generally, low-scoring questions were those requiring higher-thinking skills to analyze patterns or apply basic knowledge to make predictions (Figure 3). No student approximated the ideal response in three questions (9, 10B, and 10C). A further six of the ten questions (3, 5, 6, 8, 10A, and 10D) saw less than 1% of responses at the highest level (Score 3). Question 2 received the greatest relative proportion of high scores while question 8 was dominated by a large number of low scores.

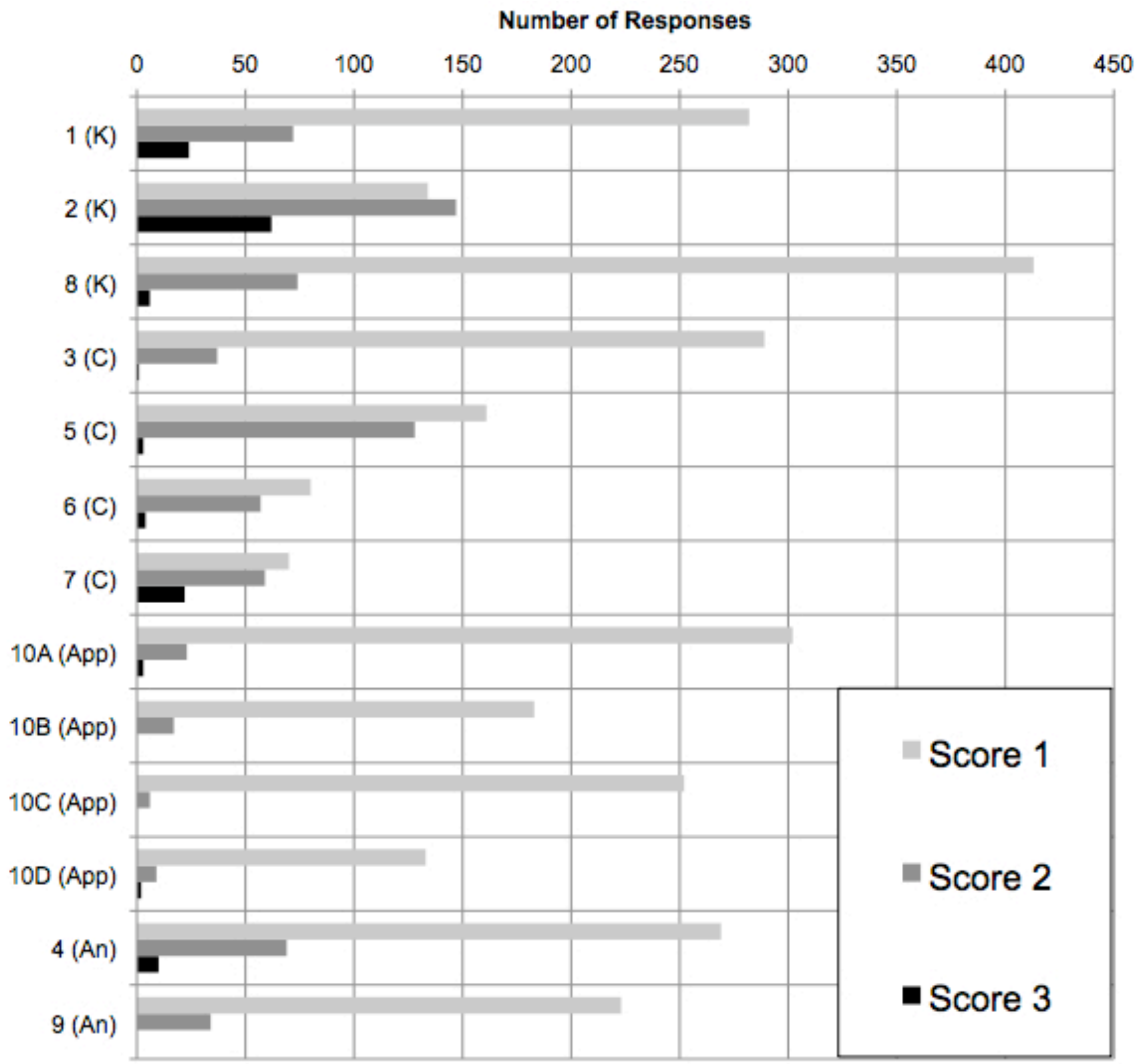

Figure 2.3: Distribution of scored responses to each VCS question, grouped by Bloom's Taxonomy: knowledge = K, comprehension = C, analysis = An, application = App. High-scoring responses are most common in the lower levels of the cognitive domain.

Question 4 addressed the locations of volcanoes around the world and asked students to think about what might be controlling their distribution. It should be noted that students were not provided with any visual aid (maps, diagrams, etc), but rather were expected to construct their own conceptual imagery. While exposure to global volcanic, earthquake, and tectonic maps may promote connection between these phenomena, the goal of this survey was to assess base levels of prior student knowledge at the beginning of introductory geology courses without support material. In total, 512 students offered an answer. Of these, roughly half (n=258) correctly responded that there was indeed a pattern in the global distribution of volcanoes and, furthermore, indicated that this pattern was related to tectonic activity. The following are random examples of high-scoring responses:

" ... most are located where tectonic plates meet, but a few are located on hotspots"
"... around edges or the hot spots of the tectonic plates with high volcanic activity"
"Ring 'O Fire! Volcanoes often pop up at tectonic plate boundaries and hot spots"

In contrast, about the same number of students (n=254) failed to recognize a global distribution pattern of volcanoes and/or accurately describe the mechanism (tectonics) in control of that pattern (Table 4). Several types of preconceptions were apparent, the most predominant being a connection of volcanoes with bodies of water and/or the belief that all volcanoes form on islands. This group accounted for nearly 17% of the total responses. The second most common preconception (15.2 %) associated volcanism with "hot" or "tropical" climates, typically near the equator. Over 6% of the responses indicated that students believe volcanoes form due to "rough, "rocky," or "mountainous" terrain. Finally, 11% of students stated that there was no pattern or that volcanic formation was entirely random.

Analyses utilizing total score as an index of understanding found that male students (Mean Score = 7.838) performed better on the VCS than female students (Mean Score = 6.090). Caucasian students overwhelmed the population and, together with students in the "other" category, accounted for most of the highest scores. Small sample sizes complicate the interpretation of scores among most minority groups, but it appears that Native American students also score highly. The overall effects of ethnicity on total score are summarized in Figure 4. Geographical location also appears to be a significant factor: students from Western Washington University, the only participating school in a volcanically active area, performed much better than those from other schools (Figure 5). Students who claimed to be very interested in science did much better (Mean Score = 7.466) than those who were not (Mean Score = 5.365).

Pop = 512	**Hydro**	**Climatic**	**Terrain**	**Random**	**Total**
n	87	78	33	56	254
Sub %	34.3	30.7	12.9	22.1	100
Pop %	17.0	15.2	6.5	10.9	49.6

Table 2.4: Prevalence of preconceptions regarding global pattern of volcanoes (Question 4, Table 1). Subgroup proportion (Sub%) is relative to the subgroup of responses that held some form of misconception. Pop % is relative to all 512 responses to Question 4.

A t-test comparing the general education course and the course for science majors at Fort Valley State University showed that the difference in total score was significant ($p = 0.022$), with science majors performing better. Analysis of the entire data set confirmed this trend (Figure 6). Science Technology Engineering and Math (STEM) majors (including Engineering/Technology, Life Science, Mathematics, and Physical Sciences) perform significantly better than non-STEM majors ($p < 0.0001$). On average, physical and natural science majors received higher scores than other groups. In contrast, education majors received the lowest scores among the seven major categories.

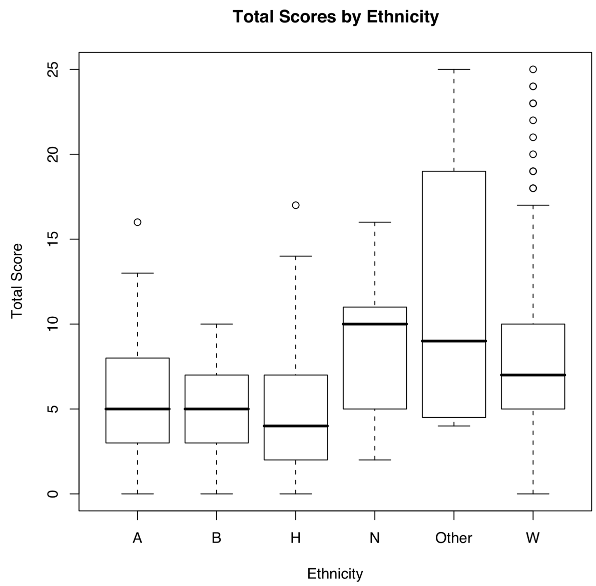

Figure 2.4: Boxplots showing the relative distribution of total scores by racial identity/ ethnicity. Blank = No response (n=12), A = Asian/ Pacific Islander (n=34), B = African American/ Black (n=55), H = Hispanic/ Latino/a (n = 102), N = Native American/ Alaskan Native (n = 9), W = Caucasian/ White (n = 456).

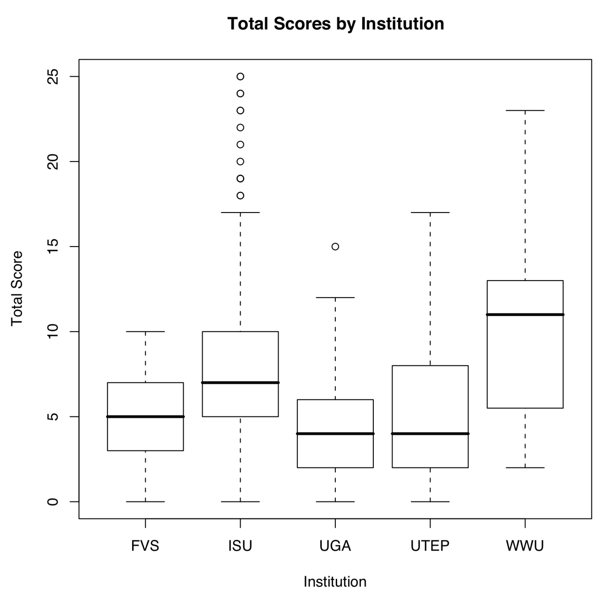

Figure 2.5: Boxplots showing the relative distribution of total scores by home institution. FVS = Fort Valley State (n = 38), ISU = Iowa State University (n = 432), UGA = University of Georgia (n = 72), UTP = University of Texas - El Paso (n = 103), WWU = Western Washington University (n = 27).

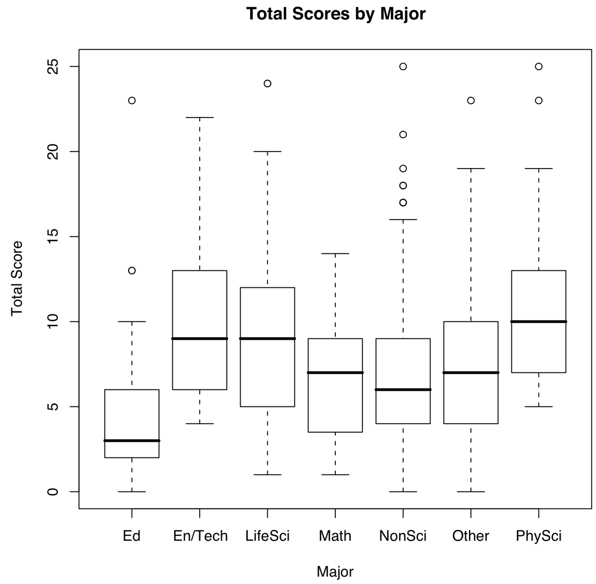

Figure 2.6: Boxplots showing the relative distribution of total scores by major. Ed = Education (n = 69), En/Tech = Engineering and/or Technology (n = 24), LifeSci = Biology (n = 51), Math = Mathematics/ Statistics (n = 24), Non-Sci = Humanities or other Non-Science (n = 434), Other = No option selected (n = 45), PhySci = Physical or Natural Sciences (n = 25).

Discussion

To analyze the conceptual objectives of each question and the responses, we ranked them using Bloom's Taxonomy (Figure 2; Bloom, 1956). This helped separate questions that could be effectively answered with only basic content knowledge from those that required higher-thinking skills such as the application of knowledge to analyze patterns or predict hypothetical results. For example, both question 2 and 3 (Table 1) obtained a similar percentage of non-zero responses. However, question 2 obtained a significant portion of high scoring responses while low-scoring responses to question 3, which required some measure of higher thinking, were predominant. Question 2, designed to address basic knowledge about what differentiates lava and magma and ranking at the lowest level of Bloom's Taxonomy, saw the overall highest proportion of Level 3 responses suggesting a general mastery of this concept. In contrast, question 3 assessed the understanding of the interior structure of a volcano as seen in cross-section. Ranking just one level higher in Bloom's Taxonomy than question 2, this concept saw very few high-scoring responses. A similar trend was observed throughout the instrument. The questions requiring only basic levels of content knowledge or comprehension (specifically questions 1, 2, 7 and 8) were more likely to obtain high scores.

Items that consistently obtained low scores include question 3, 6, 9, and 10 (Table 1). Two of these (9 and 10) were ranked in the highest levels of Bloom's Taxonomy. Question 3 asked students to draw a three-dimensional cross section of a volcano. Low scores on this item indicate that most students did not understand the inner workings of a volcano well enough to represent them graphically and may indicate a difficulty with 3-D spatial thinking. Low scores on question 6 indicate a misunderstanding of what controls eruptive explosivity. Very few students mentioned silica content or magma viscosity and its correlation with eruptive style. Questions 9 and 10 saw high levels of non-response and/or non-informative responses, which obtained no points. When combined with the fact that non-zero scores on these items were at the low end of the scoring scale, this suggests that both environmental impacts and effects of eruption on human endeavors are poorly understood. While it may be true that even experts are likely to struggle with understanding the full impact of volcanism on humans and the environment, the VCS questions sought to address direct environmental hazards and realistically predictable short-term impacts on human activities.

In contrast to the general pattern, question 5 required relatively low-level thinking skills (comprehension), but still saw a distinct lack of strong responses. Only one student explicitly identified gas pressure as the driving mechanism during a volcanic eruption.

Roughly 32% of responses instead cited seismic activity. This may stem from the fact that earthquakes often occur as precursors or consequences of volcanic eruptions, although they do not cause eruptions themselves. Over 8% implicated simple overflow of magma within the chamber - similar to a free-flowing tap - suggesting misconception about the structure of Earth's interior.

Recognition of a pattern connecting volcanoes, earthquakes, and plate motions is fundamental in modern geology. Thus, it is difficult to over-emphasize the importance of making this connection. The relatively high scores on question 4 should not overshadow the significant misconceptions demonstrated by nearly 50% of student responses (Figure 4). The most prevalent misconception attributed a global volcanic pattern to nearby bodies of water. While it is true that volcanoes form in linear belts inland from the coasts, responses in this category used language that emphasized the presence of surface water as a control mechanism and/or strictly limited the occurrence of volcanoes to islands surrounded by ocean waters. Education research has shown that viewing images and diagrams can stimulate the rapid development of mental models (Butcher and Kintsch, 2004), though the information students perceive is not always correct. Thus, it is possible that students have made an association between volcanoes and water based on the fact that many images of volcanoes in the U.S. media come from Hawaii, Montserrat, or other volcanic islands where "villagers" may be exposed to volcanic hazards.

Prior to this study, GCI data has uncovered the tendency of introductory level students to assume that volcanoes are more common near the equator (Libarkin and Anderson, 2006). While the results of the InVEST instrument suggest that association of volcanoes with water may be a more common misconception, we also confirm the strong presence of a climate-centered misconception. One student exemplified this thought by commenting: *"... where it's hotter, that's where they thrive best."* Again, this misunderstanding may be the result of the prevalence of tropical volcanism in the media.

Perhaps more significantly, over 10% of responses to question 4 explicitly stated that there was no pattern to volcanic activity or that the process was

"random." Other students (n=49) simply cited the "Ring of Fire" without further elaboration, indicating a familiarity with an important term, but little or no association of this pattern with the process driving it. It is likely that they heard about this term in grade school, but they should have also encountered the connection between plate tectonics and the global pattern of volcanoes since it is included in one of the national science education standards (National Research Council, 1996).

Even many of the best responses to question 4 did not demonstrate complete conceptual understanding. Within the subset of learners who correctly indicated that tectonic forces and/or features control global volcanic patterns, 43 inaccurately cited "fault lines", "weak spots" or "where the land is thinner". Although these factors are important in local control of volcanism, they do not account for the global pattern.

Conclusions

The use of higher-order thinking skills and abstraction appears to be a challenge for many of the students that completed the Volcanic Concept Survey. The questions receiving lowest scores are concentrated in the upper tiers of Bloom's Taxonomy. Further studies will be needed to accurately pinpoint the root cause of this observation, but at this point it appears that students do not have a deep enough understanding of volcanic concepts to deal with these high-level tasks. This might be caused by a general lack of analytical and critical thinking skills in the surveyed population. However, our instrument was designed primarily to capture understanding of volcanic processes, and thus our current data do not allow further exploration of this possibility.

Although most introductory geoscience courses are likely to contain a short unit on volcanism and plate tectonics, the limited student understanding seen on the VCS suggests that these topics should be especially emphasized. For introductory geoscience instructors at the secondary and post-secondary level, the most important implications of this study are:

1. Many students know relatively little about volcanic systems. The knowledge that they do possess is often complicated by misunderstandings about where volcanoes form, why and how they erupt, and the broad effects of eruption on Earth systems and human endeavors. The link to plate tectonics often is not understood.

2. To encourage the development of more accurate scientific ideas about volcanism and plate tectonics, existing misconceptions should be directly addressed and counter-evidence highlighted whenever possible. This may mean a careful review and discussion of graphics and examples presented in class is necessary. Instructors cannot overlook the potential for students to perceive something much different than what is intended.

3. The development of high quality materials and teaching practices is necessary to facilitate learning about volcanoes. Students who do not live in a volcanically active area are working from somewhat of a disadvantage, perhaps because volcanism has less potential to directly impact their immediate surroundings. While there is no substitute for field work and personal experience, computer simulations (e.g. Discovery Channel, 2009) may prove particularly useful to instructors in areas without active volcanism, especially when coupled with physical demonstrations (Erdogan, 2005; Harpp et al., 2005), analytical exercises (Harpp and Sweeny, 2002), and/or reflective writing strategies (e.g. Burke et al., 2006).

4. Our data show that some demographic factors have a significant impact on students' understanding of volcanoes. Male students and highly interested students tended to score better on the VCS. Other studies have concluded that male students tend to have more positive attitudes toward science (Trankina,

> 1993) and be more interested in exploring scientific topics (Jones et al., 2000). Highly interested students also did better on the VCS than those who were not interested in science, so it is possible that instructors could minimize gender effects by making an effort to stimulate interest and engagement among all students. Innovative approaches such as small-group collaboration, peer learning, hands-on exercises, and activities based on real-life experiences may make science courses more attractive to all students (Rosser, 1993).

Additionally, the score coding methodology used to analyze open-ended response in this study has broader application to geoscience education research, particularly to other instruments studying student preconceptions. The examples of student responses that we have presented could be used in the development of reliable multiple choice questions that utilize effective distractors (Libarkin and Kurdziel, 2001). Future studies utilizing the VCS will be supplemented by extensive qualitative interviews and correlation of interview data with open-ended writing and reliable multiple-choice questions. Recurrent and prevalent misconceptions will be specifically targeted in the development of an interactive Virtual Volcano teaching tool scheduled for beta testing at Iowa State University during Fall 2009. Careful studies will establish best practices for incorporating virtual environments into the classroom and explore the specific targeting of student misconceptions via interactive tools.

Acknowledgements

The authors wish to thank the undergraduate members of the Iowa State University grading team (Joe Baumann, Mitch Cline, Susan Schneck, and Amy Viner) for their assistance in coding survey responses as well as Aditya Kar for administering the survey to his students. The feedback and comments we received from Joanne Olson, reviewers Stefano Carlino and Federica Raia, and Associate Editor Wayne Powell helped us substantially improve the manuscript. Partial support for this project is provided by the National Science Foundation through award DUE-0618686.

References

Barrow, L., and Haskins, S., 1996, Earthquake Knowledge and Experiences of Introductory Geology Students: Journal of College Science Teaching, v. 26, no. 2, p. 143-146.

Bezzi, A., and Happs, J.C., 1994, Belief Systems as Barriers to Learning in Geological Education: Journal of Geological Education, v. 94, p. 134-140.

Bloom, B.S., 1956, Taxonomy of Educational Objectives. Vol. 1: Cognitive Domain: New York, McKay, 205 p.

Burke, K.A., Greenbowe, T.J., and Hand, B.M., 2006, Implementing the Science Writing Heuristic in the General Chemistry Laboratory: Journal of Chemical Education, v. 83, p. 1032-1038.

Butcher, K.R., and Kintsch, W., 2004, Learning with diagrams: Effects on Inference and Integration of Information, In: Blackwell, A., Marriott, K., and Shimojima, A., Editors, Diagrammatic Representation and inference: Third International Conference, p. 337.

Cervato, C., Rudd, J.A. II., and Wang, V.E., 2007, Diagnostic Testing of Introductory Geology Students: Journal of Geoscience Education, v. 55, p. 357-363.

Chang, C., and Barufaldi, J.P., 1999, The use of problem-solving-based instructional model in initiating change in students' achievement and alternative frameworks: International Journal of Science Education, v. 21, p. 373-388.

Discovery Channel, 2009, Volcano Explorer, http://dsc..com/convergence/pompeii/interactive/interactive.html (accessed 19 February, 2009).

Driver , R. and Odham, V., 1986, A constructivist approach to curriculum development in science: Studies in Science Education, v. 13, p. 105-122.

Erdogan, I., 2005, Controlled Volcanism in the Classroom: A Simulation, Science Activities: Classroom Projects and Curriculum Ideas, v. 42, p. 21-24.

Gonzales, P., Williams, T., Jocelyn, L., Roey, S., Kastberg, D., Brenwald, S., 2008, Highlights from TIMSS 2007: Mathematics and Science Achievement of U.S. Fourth- and Eight-Grade Students in an International Context, National Center for Education Statistics, 112 p.

Halloun, I.A., and Hestenes, D., 1985, The initial knowledge state of college physics students: American Journal of Physics, v. 53, p. 1043-1055.

Harpp, K.S., Koleszar, A.M., and Geist, D.J., 2005, Volcanoes in the Classroom: A Simulation of an Eruption Column: Journal of Geoscience Education, v. 53, p 173-175.

Harpp, K.S., and Sweeny, W.J., 2002, Simulating a volcanic crisis in the classroom: Journal of Geoscience Education, v. 50, p. 410-41.

Hestenes, D., Well, M., and Swackhamer, G., 1992, Force Concept Inventory: The Physics Teacher, v. 30, p. 141-158.

Jones, M. G., Howe, A., and Rua, M. J., 2000, Gender differences in students' experiences, interests, and attitudes toward science and scientists: Science Education, v. 84, p. 180-192.

Libarkin, J.C., and Anderson, S.W., 2009, The Geoscience Concept Inventory Version 2.1.1, https://www.msu.edu/~libarkin/gci.html (accessed 13 February, 2009).

Libarkin, J.C., Kurdziel, J.P., and Anderson, S.W., 2007, College student conceptions of geologic time and the disconnect between ordering and scaling: Journal of Geoscience Education, v. 55, p. 413-422.

Libarkin, J.C., and Anderson, S.W., 2006, The Geoscience Concept Inventory Version 1.0, http://newton.bhsu.edu/eps/gci.html (accessed 16 April, 2008).

Libarkin, J.C., and Anderson, S.W., 2005, Assessment of Learning in Entry-Level Geosciene Courses: Results from the Geoscience Concept Inventory: Journal of Geoscience Education, v. 53, p. 394-401.

Libarkin, J.C., and Kurdziel, J.P., 2001, Research Methdologies in Science Education: Assessing Students' Alternative Conceptions: Journal of Geoscience Education, v.49, n.4, September, 2001, p. 378-383.

Marques, L., and Thompson, D., 1997, Misconceptions and conceptual changes concerning continental drift and plate tectonics among Portugese students aged 16-17: Research in Science and Technological Education, v. 15, p. 195-222.

McConnell, D.A., Steer, D.N., Owens, K.D., Knott, J.R., Van Horne, S., Borowski, W., Dick, J., Foos, A., Malone, M., McGrew, H., Greer, L., Heaney, P.J., 2006, Using Conceptests to Assess and Improve Student Conceptual Understanding in Introductory Geoscience Courses: Journal of Geoscience Education, v. 54, p. 61-68.

Muthukrishna, N., Camine, D., Grossen, B., and Miller, S., 1993, Children's alternative frameworks: Should they be directly addressed in science instruction?: Journal of Research in Science Teaching, v. 30, p. 233-248.

National Research Council, 1996, National Science Education Standards: Washington D.C., National Academy Press, 272 p.

National Assessment Governing Board, 2008, Science Framework for the 2009 National Assessment of Educational Progress: Washington, D.C., US Department of Education, 155 p.

Parham, T., Cervato, C., Reed, J., Keane, C.M., Peart, L., Ross, M., Scotchmoor, J.G., Seber, D., Snyder, W.S., and Springer, D., 2005, The CHRONOS Online Questionnaire on Geologic Time and Earth History for 6-12 Grade Students and Teachers: A first step towards a succesful community-based E&O Program: Geological Society of America Abstracts with Programs, v. 37, no. 7, p. 148.

Rosser, S.V., 1993, Female-Friendly Science -- Including Women in Curricular Content and Pedagogy in Science: The Journal of General Education, v.42, n.3, p. 191-220.

Shrout, P.E., and Fleiss, J.L., 1979, Intraclass correlations: Uses in assessing rater reliability: Psychological Bulletin, v. 86, p. 420-428.

Trankina, M. L., 1993, Gender differences in attitudes toward science: Psychological Reports, v. 73, p. 123-130.

CHAPTER 3. IS HOLLYWOOD TO BLAME FOR STUDENTS' POOR UNDERSTANDING OF VOLCANOES AND PLATE TECTONICS?

A paper in preparation for submission to the Journal of College Science Teaching

Thomas L Parham Jr., Cinzia Cervato, William A. Gallus Jr.,
Michael Larsen, Jon Hobbs, and Thomas Greenbowe

Abstract

Many students are learning about volcanoes from non-traditional sources, including Hollywood films, which may be partially responsible for their poor understanding of Earth science concepts.

Introduction

The National Science Education Standards recommend introducing students to volcanism and plate tectonics as early as in grade 5 (National Research Council, 1996 p. 159). Still, studies in geoscience education (e.g., Barrow and Haskins 1996; Libarkin and Anderson 2005) have found that even undergraduate students tend to have a limited understanding of the geological processes related to plate tectonics, earthquakes, and volcanism. Most recently, the Interactive Virtual Earth Science Teaching (InVEST) Volcanic Concept Survey (Parham, et al. submitted) documented a number of misconceptions related to volcanoes. Of particular note was the inaccurate idea that volcanic eruptions were caused by changes in atmospheric conditions (i.e., increased temperature or severe weather). Also, most students failed to perceive the causal link between volcanism and tectonic plate motions - a foundational concept in modern geology. If these concepts are meant to be taught before students enter high school, why do so so many misconceptions persist among undergraduates?

It has been argued that conceptual gaps and misconceptions, particularly in the geosciences, may result from viewing mainstream science fiction and adventure films (Barnett 2006). In this study, we explore this hypothesis via the self-reported source of knowledge (SoK) of 672 undergraduate students who completed the Volcanic Concept Survey (VCS). When students were asked to identify the source from which they had learned the most about volcanoes, Hollywood films and popular media accounted for over 40% of responses. Students who learned from traditional sources of knowledge (in class or through personal experience) demonstrated much deeper and fuller understandings of volcanic systems and, thus, scored highly on the VCS. However, students who learned from non-traditional sources of knowledge, particularly mainstream films, did not score as well. So, is Hollywood to blame for misinforming the next generation of students? Moreover, what can instructors do to counter these potentially harmful film and media influences?

Methods

Survey structure and student population(s)

Five U.S. institutions administered the VCS during the first week of introductory-level geoscience courses in the fall of 2006. The conceptual survey portion featured ten free-response questions designed to assess a variety of concepts related to volcanic systems. Similar methods of assessment have been used to measure student understanding of difficult concepts in the geosciences (Libarkin and Anderson, 2005; Cervato et al., 2007) and other disciplines. Physics, in particular, has enjoyed a long tradition of robust research on student preconceptions, largely pioneered by the now famous Force Concept Inventory (Hestenes et al., 1992).

A demographic questionnaire included with the VCS recorded data including gender, age, racial identity, home institution, year in school, major, and level(s) of parental education for each student in the survey population. Overall, the survey population was 53.1% female and 46.9% male, with an average age of twenty. Students from racial minority groups accounted for roughly 30% of the total population. Humanities and other non-science majors represented 64% of the students surveyed, while less than 4% reported a major in physical sciences.

Determining Source of Knowledge

The "source of knowledge" (SoK) prompt, featured at the end of the conceptual survey, asked students to identify one out of five suggested sources from which they learned the most about volcanoes. Choices included the following:

- Hollywood Movies (e.g. Volcano, Dante's peak)
- Documentary Films (e.g. Discovery Channel)
- TV News, Newspapers, Magazines
- Classroom Activities or Textbooks
- Personal Experience or Discussion

Despite the specific directions, many students chose to select more than one source, which may indicate an uncertainty of which was most significant in their own learning. Thus, all responses were retained and considered equally valid throughout all further analyses. For example, a student selecting both films and in-class learning as significant sources of knowledge would have been included in both "movies" and "class" SoK response counts. Multiple selections prevented the characterization of distinct SoK sub-populations, but the data still proved statistically testable.

Survey scoring and analysis

In total, six hundred and seventy-two completed surveys were scored by a team of specially trained graders including three undergraduates, one graduate student, and three faculty members. Using a rubric developed in collaboration with a volcanologist and science education experts, responses were assigned individual item scores ranging from 0 to 3, based on the level of conceptual understanding demonstrated. Item scores were then compiled into a total score on the survey, which ranged from zero to a possible 30 (Highest observed score = 25, for more detailed scoring results see Parham, et al submitted). Preliminary analyses confirmed a high degree of grader reliability with respect to both item scores and total score.

Results

Student SoK Responses

Table 1 shows the relative frequency of each of the five SoK responses. Several choices were abbreviated in final reports. For example, the "TV News, Newspapers, Magazines" response was labeled simply as "Media". For the purposes of this study, "traditional" sources of knowledge included classroom activities and learning from textbooks, personal experience and/or discussion, whereas "non-traditional" sources included movies and popular (i.e. non peer-reviewed) media. Documentary films were also included in the "traditional" category. Responses indicate that many students believed they hard learned the most about volcanoes from sources in the non-traditional category. While there were multiple SoK selections across categories, in-class learning was most predominant. Still, learning from non-traditional sources proved rather pervasive. Taken as a group, non-traditional sources accounted for 40.74% of all selections.

Source	Count
Movies	215
Documentaries	174
Media	84
Class	237
Experience	24

Table 3.1: Relative Frequency of Source-of-Knowledge (SoK) Responses

Effects of SoK on Understanding

High total score on the InVEST instrument represents a broad and well-developed understanding of volcanic systems (Parham et al., submitted). Thus, we used total score to explore the effects of non-traditional sources of knowledge on students conceptualization of volcanoes and plate tectonics. Table 2 presents a multiple linear regression model developed for the entire survey data set. In this model, low p-value represents the significance of a given variable as a predictor of higher score.

	Estimate	**Std. Error**	**t-Value**	**Pr(>|t|)**
(Intercept)	5.47	0.40	13.57	0.00 ***
SoK = Class	1.44	0.43	3.37	0.00 ***
SoK = Doc	2.38	0.45	5.32	0.00 ***
SoK = Exp	3.27	0.95	3.43	0.00 ***
SoK = Media	1.05	0.54	1.94	0.05 *
SoK = Movies	0.14	0.45	0.31	0.76

Table 3.2: Simple multiple linear regression model. Residual Standard Error = 4.336 on 660 degrees of freedom. Mulitple R^2 = 0.07193. P-Value: 1.859e^{-09}. Significance: *** = p < 0.001, ** = p < 0.01, * = p < 0.1 Learning from media and movie sources are not reliable predictors of better understanding.

In this model, source of knowledge alone explained just over 7% of total score variability among all students surveyed. Traditional sources including in-class learning, personal experience, and even documentary films were highly significant predictors of a high score on the instrument, even at the $p < 0.01$ level. In contrast, both sources in the non-traditional category were not significant ($p < .01$). The p-value for media (0.052393) indicated marginal significance at the $p < .05$ level, but learning from movies was decisively not a significant predictor of high score on the InVEST instrument.

To further explore this trend, we developed an expanded linear multiple regression model, which accounted for a greater proportion (31%) of overall score variability (See Table 3). Again, learning from traditional sources predicted better understanding of volcanoes and plate teconics, even at the $p < 0.01$ level. Learning from non-traditional sources proved even less significant in the expanded model - neither media nor film sources were strong predictors of high score. Aside from source of knowledge, certain demographic factors were associated with high score. Students who were very interested in science (V.I. Sci.), or had a father with at least a high-school diploma (Father HS) performed better than their peers. Young students (specifically sophomores) and students from one of the participating institutions (Western Washington University) also scored highly on the InVEST instrument. We had anticipated racial effects with the inclusion of Fort Valley State University, an historically African-American school, and the largely Hispanic population of University of Texas - El Paso. However, racial identities were highly associated with the students' home institution, which proved much more predictive in our model.

	Estimate	Std. Error	t-Value	Pr(>|t|)
(Intercept)	1.98	0.87	2.27	0.02*
SoK = Class	0.96	0.38	2.52	0.01*
SoK = Doc	1.28	0.41	3.16	0.00***
SoK = Exp	2.41	0.84	2.86	0.00***
SoK = Media	0.58	0.48	1.20	0.23
SoK = Movies	- 0.11	0.40	- 0.27	0.79
Sex = M	1.01	0.31	3.20	0.00***
Yr = Jr	- 0.73	0.43	- 1.69	0.09*
Yr = So	- 0.87	0.39	- 2.26	0.02*
Yr = Sr	- 0.51	0.51	- 1.00	0.32
School = ISU	1.23	0.70	1.75	0.08*
School = UGA	- 0.47	0.84	- 0.56	0.58
School = UTP	- 0.74	0.82	- 0.90	0.37
School = WWU	5.78	1.07	5.40	0.00***
V.I. Sci.	2.64	0.39	6.70	0.00***
Father HS	1.63	0.53	3.08	0.00***
ID = B	3.69	0.57	6.46	0.00***
ID = C	2.32	0.56	4.12	0.00***
ID = J	1.78	0.56	3.18	0.00***
ID = M	2.92	0.87	3.35	0.00***
ID = S	0.21	0.49	0.43	0.67
ID = T	1.34	0.53	2.54	0.01*

Table 3.3: Expanded multiple linear regression model. Residual standard error = 3.778 on 644 degrees of freedom. Multiple $R^2 = 0.3127$. P-value < $2.2e^{-16}$. Significance: *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.1$

Discussion

This study included a broad sample of over 650 students from a variety of demographic backgrounds. The institutions administering the survey represented a variety of institutional types including a large Research-1 university (ISU) and a small regional university (WWU). Overall, the students surveyed were typical of what one might expect in an introductory geoscience course. What was unexpected, however, was their relatively poor understanding of volcanoes and plate tectonics. We propose that the low levels of understanding seen on the InVEST instrument stem from the source of students' prior knowledge - specifically, the tendency of many students to learn from films and the popular media.

Beyond source of knowledge, many of the significant factors in the our prediction model have been previously explored in science education and educational psychology literature. Studies have shown that males tend to be more drawn to the material rewards of scientific careers (Morgan, et. al, 2001), have more positive attitudes toward science (Trankina, 1993), and are generally more interested in exploring scientific topics (Jones et al., 2000). This implies that the interest level variable, while often statistically complex, is most likely being influenced by a gender effect. Moreover, paternal education is likely tied to socioeconomic status, which is a consistent predictor of high academic achievement. Finally, it should be noted that WWU is located in a volcanically active area, while all other institutions in the survey are not. Thus, it seems reasonable to expect that students from WWU would know more about volcanoes simply by virtue of living near them. Why sophomores would score better on the VCS is not so easily explained, and may merit future study.

Conclusion

Above all, the most significant conclusions of this study are these:

- Students who reported that they learned most about volcanoes form a traditional SoK (i.e. coursework or personal experience) were very likely to demonstrate a high level of understanding about volcanic systems.

- Students who reported that they learned most about volcanoes from a non-traditional SoK (i.e. Hollywood films and the media) were *not at all* likely to demonstrate a high level of understanding about volcanic systems.

So ... Is Hollywood to blame?

We have shown a very strong association between learning from non-traditional sources and a poor understanding of volcanoes and plate tectonics. Recent research has found that even a single viewing of modern science-fiction films can have lasting impact on students' ability to understand science content. For example, Barnett and colleagues (2006) found that watching the science-fiction film "The Core" even once led students to develop exceptionally durable, if completely inaccurate, understandings of the structure of the Earth. Together, these findings suggest that mainstream media exposure is facilitating the development of misconceptions by providing inaccurate information in an exceptionally convincing format.

Moreover, the unusual durability of these inaccurate ideas may be due, in part, to a self-perpetuating lack of scientific literacy among students. Science fiction films have been specifically cited as a cultural barrier to developing a "scientifically literate citizenry" (National Science Foundation, 2000). Without the skills to critically analyze what appears on the screen, students will continue to accept what they see as accurate information, provided it is "realistic" enough. Whereas scientists may define very different criteria for realism in a simulated volcanic eruption, students are likely to decide whether to accept or reject information based largely on perceptual cues (Prince, 1996). Perceptual realism is based largely on aesthetic criteria, and thus does not take into account the validity of any underlying processes. In this regard, advanced computer-generated graphics and effects are granting the media and mainstream films an ever-increasing power to misinform.

Bridging the Gap

While there is no substitute for real experience in the field, field trips and field-based strategies are not always viable in all settings. We must also come to terms with the fact that many students in the current generation are more comfortable learning in front of a screen than in front of a chalkboard. New teaching tools and pedagogical strategies may do well to communicate via the medium with which students are most comfortable. Using high-fidelity graphical and virtual environment simulations could appeal to students' desire for perceptual realism. However, such tools must also be backed by scientifically useful features such as real-time data logging (even if the data is entirely simulated), if they are to have any long-term utility in the classroom. Interactive parameter controls are also likely to maximize the potential for learning (Ferguson and Hegarty, 1995), while giving students an opportunity for free inquiry and exploration in simulated environments. Secondary animations or callout diagrams of important underlying mechanisms may also be quite beneficial when visualizing complex processes. Recent research in scientific visualization is exploring the implementation of callout diagrams and "illustrative 2-D shadows" in a 3-D environment (Ritter et al., 2003.

Above all, however, we cannot overlook the role of the teacher. It is interesting that geologists (and other scientists) in mainstream films often benefit from a measure of perceived authority which students are, ironically, hesitant to grant real-world research scientists and faculty. In the Barnett study (2006), for example, students' misconceptions were largely rooted in the perceived credibility of the main character, a professor of geology. When pushed, students reverted to what they had been told by the character in the film rather than the ideas put forth by their own professors. Teacher interactions provide an opportunity to simultaneously establish content expertise and encourage student development of much-needed critical thinking and metacognition skills. Specific attention should be paid to the use of thought-provoking questioning patterns that place an emphasis on the analysis of on-screen phenomena. Several written strategies, such as the Science-writing heuristic (e.g., Burke et al., 2006) may be used to support this goal.

Without doubt, modern films and the popular media have become particularly efficient at blurring the line between scientific reality and science-fiction fantasy (Frank, 2003). It now falls to college science teachers, armed with updated visualization technologies, to re-established the criteria that separate the two.

References

Barnett, M, Wagner, H., Gatling A., Anderson, J., Houle, M., and Kafka, A. 2006. The Impact of Science Fiction Film on Student Understanding of Science. *Journal of Science Education and Technology* 15 (2): 179-191.

Barrow, L.H., and Haskins, S. 1996. Earthquake knowledge and experiences of introductory geology students. *Journal of College Science Teaching* (26): 143-146.

Burke, K.A., Greenbowe, T.J., and Hand, B.M. 2006. Implementing the Science Writing Heuristic in the General Chemistry Laboratory. *Journal of Chemical Education* (83): 1032-1038.

Cervato, C., Rudd, J.A. II., and Wang, V.E. 2007. Diagnostic Testing of Introductory Geology Students *Journal of Geoscience Education* (55): 357-363.

Ferguson, E.L., and Hegarty, M. 1995. Learning with real machines or diagrams: Application of knowledge to real-world problems *Cognition and Instruction* (13): 129-160.

Frank, S. 2003. Reel reality: Science consultants in Hollywood *Science as Culture* 12 (4): 427-443.

Hestenes, D., Well, M., and Swackhamer, G. 1992. Force Concept Inventory *The Physics Teacher* 30: 141-158.
Jones, M. G., Howe, A., and Rua, M. J. 2000. Gender differences in students' experiences, interests, and attitudes toward science and scientists *Science Education* (84): 180-192.

Libarkin, J.C., and Anderson, S.W. 2005. Assessment of Learning in Entry-Level Geosciene Courses: Results from the Geoscience Concept Inventory *Journal of Geoscience Education* (53): 394-401.

National Research Council (NRC). 1996. *National Science Education Standards.* Washington, DC: National Academy Press.

National Science Foundation (NSF). 2000. *Indicators: Science and Engineering 2000*. Washington, DC: National Science Foundation.

Prince, S. 1996. True lies: Perceptual realism, digital images, and film theory *Film Quaterly* 49(3):27-37.

Ritter, F., Sonnet, H., Hartmann, K., and Strothotte, T. 2003. Illustrative shadows: integrating 3d and 2d information displays. *In IUI '03: Proceedings of the 8th international conference on Intelligent user interfaces*. 166-173. New York, ACM Press.

Trankina, M. L. 1993. Gender differences in attitudes toward science *Psychological Reports* (73):123-130.

CHAPTER 4. GENERAL CONCLUSION

Discussion

Recent work has explored how students often struggle to conceptualize the "complex dynamics" of Earth systems. As we have seen, the nature of student understanding (or misunderstanding) about volcanic systems is every bit as complex as the dynamic forces driving the volcanoes themselves. Generally, results from the VCS have shown that, among American undergraduates, many key concepts related to volcanism are poorly understood. The aspects of volcanic systems that student do fully grasp are typically limited to basic terminology (i.e. lava vs. magma) or typology (volcano shape). In contrast, students struggle to understand eruption mechanics, the connection of eruptions to tectonic plate motion, and the interactions between volcanic eruptions and the environment and/or human activities. Student preconceptions in these areas are extensive enough that specific remediation efforts in the classroom may be necessary to promote conceptual change.

In-depth exploration of student demographics has provided some insight as to where students' inaccurate ideas may be coming from. Over 40% of students reported learning about volcanoes primarily from non-traditional sources, but analysis of VCS data demonstrated that students who learned from non-traditional sources did not have as accurate, nor as well-developed, an understanding of volcanic systems when compared to their peers. The durability of media-generated misconceptions may be due to the media's powerful ability to appear perceptually realistic. While existing tools and strategies may help to promote conceptual change, new learning tools and visualizations will be required if classrooms are forced to compete with the persuasive power of modern film and media.

Perhaps one of the most significant contributions of this research is the collection of preliminary data needed for student-centered development of a new Virtual Volcano teaching tool. Having an idea of what aspects of volcanism students do not understand has informed the basic design of the new software. For example, two cases currently being modeled in Virtual Volcano were selected specifically to provide counter-evidence against students' preconceptions that volcanoes form only in hot places or are connected with oceanic surface waters. Selected parameter controls, which are currently in development, will allow students to control and explore eruption processes. Virtual Volcano is still a work in progress, but information from these preliminary studies should help the InVEST team develop the best teaching tool possible.

Of course, the continuous study of what students in geology courses know and how they learn will always be the bedrock on which the scholarship of geoscience education is built. Thus, the VCS instrument will continue to be developed and improved in its future iterations, and will continue to support future scholarship. Future studies in association with Virtual Volcano will employ VCS-based assessment and qualitative data from student interviews to develop inquiry-driven explorations of the simulation and associated volcanic phenomena. A primary goal in geoscience education scholarship should always be to help improve the quality of instruction educators provide to their students. By offering students the best educational experiences possible, we help the next generation of professionals, scientists, and citizens develop a much-needed appreciation of the natural world.

Acknowledgements

I would like to take this opportunity to express my thanks to those who assisted me in conducting this research and helped with the writing of this thesis. First and foremost, I thank Dr. Cinzia Cervato for her guidance, patience and support. Her insights and constructive criticism have often inspired me and helped sharpen the focus of my research. I would also like to thank my committee members for their efforts and contributions to this work: Dr. William Gallus for his coordination of communication with the Virtual Volcano team, Dr. Michael Larsen for his assistance with statistical analyses, and Dr. Greenbowe for the recommendation of excellent coursework in my graduate program. I would also like to thank Dr. Pete Stelling for providing his expertise as a volcanologist, and Jon Hobbs for his clarification of our statistical results. Finally, I would additionally like to thank all my committee members and the entirety of the InVEST project team for their review of our manuscripts and much-appreciated feedback throughout the writing process.

APPENDIX. THE VOLCANIC CONCEPT SURVEY (VCS)

Demographic Questionnaire

1. Gender: ☐ Male ☐ Female

2. Age:

3. Country:

4. State *[if applicable]*:

5. *[Optional]* For statistical purposes, please indicate your racial identity or ethnic group:

(Choose all that apply):

- ☐ American Indian, Alaska Native
- ☐ Asian, Pacific Islander
- ☐ Black, African-American
- ☐ Hispanic, Latino
- ☐ White, Caucasian
- ☐ Other: __________

6. Year in college (please circle):

Fr. Soph. Junior Senior Other

7. How would you classify your major?

(Choose all that apply):

- ☐ Physical Science (Physics, Chemistry, Geology)
- ☐ Life Science (e.g. Biology, Agriculture)
- ☐ Engineering/ Technology
- ☐ Mathematics
- ☐ Humanities or other Non-Science
- ☐ Other: __________

8. How would you classify the environment in which you attended school for grades 6-12?

- ☐ Urban public school
- ☐ Urban private school
- ☐ Suburban school (public or private)
- ☐ Rural schools (public or private)

9. Please record the grade level in which you **most recently** took the following classes before college:

Biology:	6	7	8	9	10	11	12
Chemistry:	6	7	8	9	10	11	12
Earth Science:	6	7	8	9	10	11	12
Physics:	6	7	8	9	10	11	12

10. Which is the highest level of education that your <u>Mother</u> completed?

- ☐ Some high school
- ☐ High school diploma
- ☐ Some college/vocational
- ☐ Bachelor's Degree
- ☐ Graduate Degree (Master's, PhD, etc.)
- ☐ Don't know

11. Which is the highest level of education that your <u>Father</u> completed?

- ☐ Some high school
- ☐ High school diploma
- ☐ Some college/vocational
- ☐ Bachelor's Degree
- ☐ Graduate Degree (Master's, PhD, etc.)
- ☐ Don't know

Please respond to the following statements about science:

12. To me, science in general is:

- ☐ Very interesting – a favorite subject
- ☐ A somewhat interesting subject
- ☐ The same as any other subject
- ☐ Not particularly interesting
- ☐ Not at all interesting – a waste of time

13. I'm interested in learning about the Earth and how it works

- ☐ I'm very interested
- ☐ I'm somewhat interested
- ☐ I'm indifferent
- ☐ I'm not overly interested
- ☐ I'm not interested at all

Please tell us about your experience with the use of technology:

14. I feel _______ comfortable surfing the web for information.

- ☐ Very
- ☐ Fairly
- ☐ Moderately
- ☐ Not very
- ☐ Not at all

15. I play video/ computer games:

- ☐ Frequently – Almost every day
- ☐ Sometimes – Once or twice a week
- ☐ Only occasionally – Every few weeks
- ☐ Rarely – Once a month or less
- ☐ Never – Once a year or less

Please tell us how you would learn best in the following situations:

Remember, these are your choices.
There is no right or wrong answer.

16. You want to learn a new computer program. What would you do first?

- ☐ Sit down at the keyboard and experiment
- ☐ Carefully read the instruction manual
- ☐ Telephone or text a friend to ask questions

17. You are staying in a hotel and have a rental car. You would like to visit friends whose address/location you do not know. What would you like them to do?

- ☐ Provide you a map on paper or via the web
- ☐ Write down the directions (without a map)
- ☐ Tell you the directions over the phone
- ☐ Pick you up from the hotel

18. You are starting a new class. Which type of teaching do you hope the professor uses most?

- ☐ A standard textbook, handouts and readings
- ☐ Charts and graphs, PowerPoint, videos, etc
- ☐ Field trips, models, labs, and practical tests
- ☐ Class or email discussion, chat, or speakers

19. Recall a time in your life when you learned a new skill. Try to avoid choosing something physical, e.g. riding a bike. I learned best by:

- ☐ Visual clues – pictures, diagrams and charts
- ☐ Written instructions.
- ☐ Listening to someone give instructions
- ☐ Doing it or trying to do it

Concept Inventory: Volcanoes

Please answer the following questions about volcanoes and volcanic eruptions.

1. Are all volcanoes similarly shaped? If not, how many distinct shapes can be seen? (Please illustrate your ideas below)

2. What is the difference between lava and magma?

3. Describe the composition of a typical volcano. In other words, if you could cut a volcano in half, what would you see on the inside?

4. Think about the location of volcanoes on land around the world. Is there a pattern to their location, and if so, what might control that pattern?

5. Why does a volcano erupt?

6. What controls how explosive a volcanic eruption will be?

7. How does water in a volcanic system affect how explosive a volcanic eruption will be?

8. Draw a picture of an erupting volcano and identify as many features as you can.

9. Volcanic eruptions can create natural hazards beyond the eruption of lava and ash. In the left column, list hazards directly caused by erupted material. In the right column, identify hazards caused by the interaction of these materials with their surrounding environment.

Eruption Material Hazards	Environmental Interaction Hazards

10. As **specifically as possible**, describe how a volcano might affect the following people or groups of people in the region:

a. A farmer living at the base of the volcano:

b. A tourist lodge along a stream flowing down from the volcano:

c. A pilot of a 747 flying through an area above the volcano:

d. A group of skiers on the side of the volcano:

11. Where would you say you have learned the **most** about volcanoes?

- ☐ Hollywood movies (e.g. Volcano, Dante's Peak)
- ☐ Documentary films (e.g Discovery Channel)
- ☐ TV News, Newspapers, Magazines
- ☐ Classroom Activities or Textbooks
- ☐ Personal Experience or Discussion

12. Are there any additional questions you would like answered about volcanoes? If so, please list them below:

Thank you for participating in our survey!