INVESTIGATING IN-SERVICE EDUCATORS’ AND UNDERGRADUATES’ MENTAL TECTONIC MODELS

A thesis presented to
the faculty of
the College of Arts and Sciences of Ohio University

In partial fulfillment
of the requirements for the degree
Master of Science

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March 2007
This thesis entitled

INVESTIGATING IN-SERVICE EDUCATORS’ AND UNDERGRADUATES’
MENTAL TECTONIC MODELS

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Abstract

WUNDERLE, MARCUS S., M.S., March 2007, Geological Sciences

INVESTIGATING IN-SERVICE EDUCATORS’ AND UNDERGRADUATES’ MENTAL TECTONIC MODELS (61 pp.)

Director of Thesis: Gregory Springer

Mental models of the physical world can have profound impacts on how people view the Earth and Earth processes. In this study, undergraduate students (n=39) were interviewed and in-service science educators (n=110) completed questionnaires in order to examine and identify alternative conceptions about plate tectonics. Both interview protocol and questionnaires targeted conceptions about the spatial location of tectonic plates and the geographic locations of physical features and naturally occurring phenomena. Interviewees were recruited from multiple sections of introductory geology at a mid-western university. Interviews followed a semi-structured interview protocol to ensure consistency in questioning. During interviews, students were asked to express ideas verbally and diagrammatically allowing for the collection of artifacts, including drawings of Earth’s shallow interior and student generated maps. In-service science educators were recruited from across the United States using multiple National Science Teacher’s Association (NSTA) list-servers. Short, open-ended questionnaires about plate tectonics were distributed to the in-service population via e-mail. Alternative conceptions held by the study populations were determined by comparing interview (verbal & diagrammatic) and questionnaire (verbal) responses to scientifically acceptable explanations. Geographic locations of earthquakes, volcanoes, and mountains were collected from student maps and digitized in ArcMap for analysis. Using collected data, ‘student’ point
patterns were created and compared to observed locations of earthquakes. Categorization of drawings (undergraduate) and responses (educators) indicates that the majority of undergraduate students (67%) and one-third (33%) of in-service educators do not recognize that tectonic plates are at the surface of the Earth. Using a $\chi^2$-test of independence, placement of tectonic plates was also found to be dependent upon gender in both populations.

Approved:

Gregory Springer
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Acknowledgements

I would first like to thank my wonderful and extremely patient thesis advisor and project coordinator, Julie Libarkin, for her guidance and support and Greg Springer for filling my need for an advisor at OU towards the end of my project. I would also like to thank the following contributors who aided in the completion of this project: Members of my thesis committee: Alycia Stigall, Jeff Euland, and Greg Springer; research assistant and ping pong partner, Mark Zickefoose; participating undergraduate students and in-service educators; participating introductory geology instructors. Also, I need to thank David Kidder for assisting me in final submission, Greg Nadon for watching out for me and filling me in on deadlines while I was away working, and my family and friends for their continued support. Last but not least, my dog, Penny, who distracted me from my work for hours on end while attempting to finish this project.
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**Introduction**

Over the past several decades, conceptions research has become increasingly popular in the sciences including biology (Yip, 1998), and physics (Bendall et al, 1993; Preece, 1997), chemistry (BouJaoude, 1992). Relatively few studies have focused specifically on student geoscience conceptions (Delaughter et al., 1998; Gobert & Clement, 1999; Marques & Thompson, 1997; Stofflett, 1994; Trend et al., 2000). Even fewer studies have examined geoscience conceptions of in- and pre-service educators (e.g. Bendall et al., 1993; Gosselin & Macklem-Hurst, 2002; Preece, 1997). Additionally, conceptions studies have in general, and in geoscience in particular, focused on K-16 populations with very little focus on ideas held by educators.

Geoscience conceptions research has investigated *The whole Earth including Earth’s interior* (Nussbaum and Novak, 1976; Gunstone & White, 1981; Happs, 1982; Libarkin et al., 2005); *Earth and Space* (Nussbaum, 1979; Schoon, 1992; Vosniadou & Brewer, 1992); *The Water Cycle* (Meyer, 1987; Bar, 1989; Brody, 1996); *The Rock Cycle* (Stofflett, 1993; 1994); *Geologic Time* (Ault, 1982; Trend, 1998; Dodick & Orion, 2003; Libarkin et al., 2005); and *Plate tectonics* (Happs, 1982; Schoon, 1992; Bezzi & Happs, 1994; Marques & Thompson, 1997; Gobert, 2000; Trend et al, 2000; Libarkin et al, 2005; Dahl et. al., 2005).

**Study Domain**

This research investigates in-service educators’ and undergraduate students’ mental tectonic models. The research draws on current findings from student ideas about plate tectonics (Libarkin et al., 2005; Libarkin & Anderson, 2005; Marques & Thompson, 1997; Ross & Shuell, 1993), student representations of mountainous landscapes (Trend et
al., 2000), creation and interpretation of student drawings (Gobert & Clement, 1999; Gobert, 2000), categorization of student drawings and interview text (DeLaughter et al., 1998; Vosniadou & Brewer, 1992; 1994), and alternative conceptions held by pre- and in-service secondary science educators (Preece, 1997; Bendall et al., 1993). It is noteworthy that the goal of this study is to qualitatively evaluate students’ and educators’ understanding of simplified models of plate tectonics. Working with K-12 educators may provide possible insight to the severity of alternative conceptions held that may be passed on to students.

Within this study, mental tectonic models are defined as ideas about plate tectonics and the driving mechanisms behind tectonics. These conceptions may have been generated over a long period of instruction beginning at a very young age. Specifically, in the state of Ohio, plate tectonics is first introduced in grade three (Ohio Academic Content Standards K-12, p. 35). Plate tectonics has also been identified as a national benchmark standard for both middle and high schools, according to the American Association for the Advancement of Science (AAAS, 1993). Benchmarks have been set for the completion of the eighth-grade program and include students understanding that the interior of the Earth is hot. Heat flow and movement of material within the earth cause earthquakes and volcanic eruptions and create mountains and ocean basins (p. 73). By the end of the twelfth-grade program, students should recognize that the solid crust of the Earth—including both the continents and the ocean basins—consist of separate plates that ride on a denser, hot, gradually deformable layer of the
Earth. The crust sections move very slowly, pressing against one another in some places, pulling apart in other places. Ocean-floor plates may slide under continental plates, sinking deep into the Earth. The surface layers of these plates may fold, forming mountain ranges (p. 74).

Gobert (2000) determined that plate tectonics is a difficult science topic for middle school students to understand. This study included fifth grade students reading a descriptive text about plate tectonics and creating drawings to represent what was read. Libarkin et al. (2005) also concluded that college students have difficulty understanding aspects of plate tectonics. This study investigated college students’ non-scientific conceptions of the Earth using questionnaires and interviews. Understanding plate tectonics has been deemed difficult by many researchers (Ault, 1984; Gobert & Clement, 1999; Jacobi et al., 1996). Until researchers are able to comprehend why understanding tectonics is so difficult, this body of research will be continually expanding.

Previous Work

The study of plate tectonic conceptions is often embedded in broader studies about whole Earth concepts. Researchers have uncovered idea about the location of tectonic plates (Libarkin et al., 2005), the location and formation of volcanoes and mountains (Happs, 1982; Muthukrishna et al., 1993), and plate motion (Marques & Thompson, 1997; DeLaughter et al., 1998). Studies specifically exploring ideas about plate tectonics have focused on students’ understanding of plate tectonics through drawings (Gobert, 2000), drawings and summaries (Gobert & Clement, 1999), and analysis of continental drift and plate tectonics (Marques & Thompson, 1997). In

*This explanation of Earth’s crust is actually referring to the lithosphere. This is common mistake (e.g. Muthurkrishna et al., 1993).
general, researchers have explored methods for eliciting ideas from subjects via questionnaires and interviews (Libarkin et al., 2005; Ross & Shuell, 1993) and collecting, categorizing, and interpreting drawings (DeLaughter et al., 1998; Gobert, 2000; Gobert & Clement, 1999; Vosniadou & Brewer, 1992; 1994).

Studies relevant to the present research have used interviews and questionnaires to investigate alternative conceptions about tectonics. A study conducted by Libarkin et al. (2005) investigating students’ non-scientific ideas about the Earth using 265 open-ended questionnaires and 105 interviews. This study identified alternative conceptions pertaining to the Earth via thematic content analysis. Libarkin et al. (2005) discusses students’ inability to correctly use scientific terminology related to tectonics and included mental models from subjects regarding the spatial and mechanical decoupling of tectonic plates from Earth’s surface.

Ross and Shuell (1993) interviewed ninety-one K-6 students’, living in three different geographic locations, regarding their beliefs about earthquakes. Students were asked to define the term ‘earthquake’ and explain what causes earthquakes. Results indicated that children acquire knowledge about the natural world prior to instruction. For example, K-3 students who were not exposed to instruction about tectonics were able to respond to questions about earthquakes from watching media coverage of a recent earthquake. Also, it was hypothesized by Ross & Shuell (1993) that misconceptions may persist post-instruction because of the use and misuse of scientific language in everyday conversation. They propose that educators should monitor the use of and understand the meaning of scientific terminology in lessons has been made.
Other studies have used additional methods along with interviewing to elicit ideas about the Earth (e.g. DeLaughter et al., 1998; Gobert & Clement, 1999; Gobert, 2000; Trend et al., 2000). In these studies, student drawings used to categorize students’ mental models. DeLaughter et al. (1998) explored student preconceptions via an Earth Science Literacy Test where students were asked to answer questions and construct drawings about the whole Earth. Results indicated that student ideas differed from scientifically acceptable ideas. For example, students constructed sketches of flat layers within a spherical Earth.

Gobert & Clement (1999) explored the effects of student summaries vs. student drawings on conceptual understanding of plate tectonics. This study included 58 fifth-grade students who were asked to complete a different task (creating drawing(s), creating summaries, or simply reading text during a text reading session about tectonics) while reading a text. Student conceptual understanding was scored using a post-test assessment tool to determine which group retained a more complete understanding of the text material. Results indicated that students who created a drawing during their reading of a tectonic related text retained a more complete conceptual understanding of the domain.

To further this research, Gobert (2000) characterized interior-Earth models as well as the casual and dynamic processes involved in plate tectonic models presented by fifth-grade children. Students were given a short text about plate tectonics and prompted to create a drawing after reading each text section. Although students were not allowed to refer to the text while drawing, they were informed prior to reading that they were going to be creating a drawing about what was read. Two student models of interior Earth were identified and multiple student models were identified regarding causal and
dynamic mechanisms inside the Earth. A large percentage (89%) of students involved in this study held spatially correct models of interior Earth which was attributed to prior knowledge gained from textbooks, the media, or other sources. Models relating to causal and dynamic mechanisms involved in volcanic eruptions included local-heat related models, local-movement related models, and mixed and integrated models involving both mechanisms. Results also indicate that models (drawings), once constructed, may serve as barrier for further understanding or alternatively, when engaged in conversation about their drawings may aid in model revision.

Trend et al. (2000) reported that a drawing combined with interviews is a successful technique for exploring ideas. A study conducted by Trend et al. (2000) focused on children aged 7-11 years and reported ideas about children’s understanding of mountainous landscapes and formation. Results indicated that drawings created by 7-9 year olds were significantly different than those of 9-11 year olds in terms of perception, conceptions and priorities suggesting that age may play a role in mental model development and revision.

Methodology

Purpose

The purpose of this study was to identify and examine mental tectonic models held by in-service educators and undergraduates and to characterize these models with respect to the location of tectonic plates, the location of large, frequently occurring earthquakes, and other tectonic phenomena. This research was conducted to expand on the body of research investigating plate tectonic conceptions and to develop a new methodology for analyzing conceptual models.
Table 1a: Undergraduate Demographics

<table>
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<tr>
<th>Student Population</th>
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<td><strong>Gender</strong></td>
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<tr>
<td>Males</td>
</tr>
<tr>
<td>Females</td>
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<tr>
<td><strong>Age ranges</strong></td>
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<tr>
<td>17-18</td>
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<td>19-22</td>
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<td>23-25</td>
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<tr>
<td>&gt;25</td>
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<tr>
<td><strong>Class rank</strong></td>
</tr>
<tr>
<td>Freshman</td>
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<tr>
<td>Sophomore</td>
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<tr>
<td>Junior</td>
</tr>
<tr>
<td>Senior</td>
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<tr>
<td>other/grad</td>
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<tr>
<td><strong>Majors</strong></td>
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<tr>
<td>Education</td>
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<tr>
<td>General</td>
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<tr>
<td>Early Childhood (K-3)</td>
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<td>Middle Childhood (4-9)</td>
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<tr>
<td>Special (K-12)</td>
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<tr>
<td>Science</td>
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<tr>
<td>Sciences</td>
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<tr>
<td>Non-Science or Non-Education</td>
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</table>

Subjects

The study populations included undergraduates who were enrolled in an introductory geology course at a mid-western, U.S. university and in-service educators from across the United States. Undergraduates were recruited from multiple sections of introductory geology.

In-service educators were recruited using multiple National Science Teacher’s Association (NSTA) list-serves; therefore, the in-service population was limited to members of NSTA. Undergraduates were interviewed on campus and in-service educators were sent a questionnaire via e-mail.
In total, 39 students successfully completed an interview (18 males and 21 females), 38 of these interviewees graduated from high schools in the Ohio Valley Area, with one graduate from a New Jersey high school. All of the participating students were Caucasian and ranged in age from 17 to 25. 6 of the participants were science majors, 18 were education majors, and 15 were non-science or non-education majors. Of the 18 education majors, five were science education majors representing secondary sciences (grades 7-12), four were middle childhood science (grades 4-9) majors, four were early childhood majors (K-3), one was a special education major, and four were either general education majors or did not specify on concentration(s). Recruitment was completed with the permission of the Institutional Review Board and participating instructors of introductory geology. Students who volunteered to participate in this study received a small amount of extra-credit in the course from which they were recruited. The target population of recruitment, although not announced to possible participants, was pre-service educators (n = 18). The pre-service population was being targeted to allow connections to be made between alternative conceptions held by the in-service, undergraduate and pre-service populations.

Written responses from completed questionnaires pertaining to plate tectonics (Table 2, 3, & 5) were completed by 110 K-12 in-service educators from the United States.
Table 1b: In-Service Educators’ Demographics

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<tr>
<td>Gender</td>
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<td>Female</td>
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<td>Age</td>
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<td>Average</td>
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<tr>
<td>Low</td>
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<tr>
<td>High</td>
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<tr>
<td>Teaching Experience</td>
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<td>Average</td>
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<tr>
<td>Low</td>
</tr>
<tr>
<td>High</td>
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Average age of in-service participants was 44, ranging from the 23 years to 82 years old. Average years of teaching experience reported was 13, ranging from 0 years to 39 years of experience. 37 reported they teach all of the tectonic information covered by the questionnaire in their classrooms, 33 reported they teach none of the material, 25 reported they teach very little, 8 reported they teach most and six did not respond. Grades taught ranged from Pre-K to college level. Completion of the in-service questionnaire was completely voluntary and anonymous. 13 and 11 educators did not respond to the ‘age’ and ‘experience’ question respectively.

Reliability and Validity of Study

Reliability and validity are important parameters of a qualitative study. To ensure that this study has achieved these parameters, the following four criteria were set forth: credibility, transferability, dependability and confirmability. Credibility asks whether or not participants of a study would agree with results and conclusions. Transferability deals with result significance with regards to other populations. Dependability requires that results and procedures are repeatable and agree with results obtained in similiar
studies. *Confirmability* requires that researchers take preventative measures to ensure bias is not present in the data.

*Credibility*

Credibility is achieved by ensuring that participants would agree with findings of the study. Results of this study leave no room for participant disagreement since results were drawn directly from participant responses. Responses included written responses from in-service educators and verbal responses, drawings and maps from undergraduates.

*Transferability*

Generalizability involves the significance of study results regarding transferability to other populations or populations in alternate geographic locations (Last, 2001). Participants of this study included undergraduates and in-service educators. All undergraduate subjects were Caucasian students, predominantly from the Ohio Valley ranging in age from 17-25 who were enrolled in an introductory geology course at a mid-western university. In-service educators were predominantly Caucasian, members of NSTA from the United States varying in age from 23 to 82 and ranging in experience from novice to veteran. Results from this study are therefore significant to populations similar to the populations involved. Results drawn from undergraduate students are applicable to students enrolled in an introductory geology course at a mid-western university, aged 17-25 years. Results drawn from the in-service educator population, although limited to members of NSTA, are applicable to the general in-service population in the United States with similar experience, age and amount of plate tectonic content in their curriculum.
**Dependability**

Dependability requires that results and procedures of this study are repeatable. Additionally, do results agree with previous tectonic conception studies? Procedures were approved by an institutional review board (Appendix A) to obtain permission for use of human subjects in research. Interview procedures and protocol were modeled after a previous study where reliability and validity standards have already been met (Libarkin et al., 2005). Questionnaires were composed based upon the interview protocol. Interview protocol was based upon ideas held by study populations in previous tectonic conceptions literature and benchmark standards set forth by the AAAS and the Ohio Department of Education.

Recruitment, interview and questionnaire procedures may be repeated by any researcher who has access to students of any age and educators who are willing to complete a questionnaire. Obtaining results that agree with other tectonic conceptions studies involved asking questions related to tectonics to the study population. It is well documented that populations with varying demographics hold very similar alternate conceptions about tectonics (e.g. Gobert, 2000; Libarkin et al., 2005; Trend, 2000).

**Confirmability**

Confirmability refers to researcher bias and whether the research has taken preventative steps to ensure the least amount of bias possible. Steps taken in this study to ensure results were independent of researcher bias included coding of interview text and questionnaire responses as well as analyzing and categorizing student drawings by multiple researchers to achieve inter-rater reliability. The use of ArcMap allowed for analysis of earthquake data collected from undergraduate students. Since students were
asked to place large earthquakes on a map, student earthquake data was directly compared to observed earthquake data with magnitudes from five to ten on the Richter scale.

**Procedure**

*Interviews and Questionnaires*

All participating undergraduate students were interviewed. Interviews followed a semi-structured interview protocol (Appendix B) which included additional probing questions to ensure thorough and consistent questioning. Demographic information was collected from all participants prior to interviewing (Table 1). One video camera and an audio-tape recorder were used to capture audio and visual materials. In order to participate, undergraduates agreed to the use of audio taping. Video recording required additional consent from the participant. All data was collected in the form of audio and video recording, drawings, and student generated maps of physical features and naturally occurring phenomena.

Problematic areas in the understanding of plate tectonics were identified in the previously described literature. Areas of expected student understanding were identified from educational benchmarks and standards set forth by the State of Ohio and the AAAS. Problematic and areas of expected understanding were combined to form a semi-structured interview protocol that provided questions pertaining to plate tectonics. After creation of the interview protocol, a small pilot (n=10) study was conducted. Upon conclusion of the pilot study, changes such as addition and subtraction of probing questions were made to the protocol optimizing interviewee response. Interviews typically consisted of five initial questions, each with multiple probing questions, to
encourage in-depth responses. Although subject response was not limited items on the protocol, every interviewee responded to all protocol questions. Interviews varied in length, typically lasting approximately 35-40 minutes.

In-service educators from multiple NSTA list-servers received a short, open-ended questionnaire related to plate tectonics (Appendix D). A consent form was sent as an attachment to the questionnaire. It simply stated that by completion of the questionnaire implies that consent has been granted to use collected data in a research study. The questionnaire, like the interview protocol, was designed to elicit in-service educator ideas about mountains, earthquakes, volcanoes, and the location and composition of tectonic plates. Questionnaires did not allow for the use of multiple probing questions or drawings since we were limited to written responses only. Although simplistic, the open-ended nature of the instrument prompted responses that were generally complex and contained numerous ideas about plate tectonics.

*Interview Artifacts*

Artifacts were collected from each interview, including detailed maps (Figure 1) and drawings (Figure 2). A Robinson-projected, blank world map was given to each
Figure 1: Student’s representations of geographic locations of mountains, volcanoes, and earthquakes. Each student participant was given a world map that included only continental boundaries and was asked to draw the location of 1) mountains, 2) large, frequently occurring earthquakes and, 3) volcanoes. On most maps, the features were primarily located in North America and more specifically in the United States. Figure 1a and 1b depict students’ ideas of where mountains, volcanoes and earthquakes are located globally. Both maps contain common features and are representative of the entire undergraduate populations’ maps. It is evident in both maps that the students feel confident in saying that the western margins of North and South America contain mountains, earthquakes and at least one volcano whether or not features are placed in correct geographical location.
participating student with intent to have each student mark the geographic locations of mountains, volcanoes, and large, frequently occurring earthquakes. Each student was asked to mark the location of large, frequently occurring earthquakes and the location of mountains (Figure 1). Students were asked to mark the location of volcanoes (n=23) only if the student was interested in discussing the nature of volcanoes. Some students however did not attempt to mark the location of phenomena if he/she did not feel comfortable or did not know where to mark. In addition to the maps, each student was given blank, white drawing paper to construct drawings upon. Drawings included students’ representations of plate boundaries, continental boundaries, interior Earth, and most importantly the spatial relationship of tectonic plates and Earth’s surface. Each undergraduate participant was asked to construct a drawing that included the following (Figure 2):

(1) A person (yourself).

(2) Earth’s surface.

(3) [At least] one tectonic plate.

No particular method of drawing construction was explained to participants although the majority of students chose to construct drawings in cross-section. Interview text was used as an interpretation guide when categorizing drawings to aid in correct identification of unlabeled features and to describe thickness of drawn features.

**Analytical Methods**

*Interviews and Questionnaires*

Interview text and open-ended questionnaires were analyzed via thematic content analysis. Thematic content analysis focuses on searching for naturally emerging patterns
Figure 2: Digitally enhanced (replicas) of student drawings of the spatial location of tectonic plates relative to Earth’s surface. Each student participant was asked to make a drawing that included: 1) Earth’s surface, 2) A tectonic plate and 3) a person. Both drawings meet the criteria, but represent very different models. A) This drawing displays a student’s attempt to draw Earth’s surface in 3-dimensions in a 2-dimensional, cross-sectional display of interior Earth. The surface only includes what is on top of the ‘crust’ and the ‘plate’ lies below, not in contact with the crust (category 3). B) This drawing shows that ‘plates’ are located very deep within the Earth with a very thick ‘magma’ layer between the ‘plates’ and the surface. Also notice that the Earth’s spherical shape is defined by the surface but the layers within Earth are arranged horizontally (category 5).
in responses as described in Patton (2002). All 39 interviews and 110 questionnaires were analyzed with reference to pre- and in-service educator ideas about plate tectonics. Examples of interview and questionnaire coding can be seen in (Tables 2, 3, & 5). Since one of the goals of coding was to compare ideas of undergraduates vs. in-service educators, ideas from interview responses were compared to similar ideas from questionnaire responses. Interview coding was also used to confirm ideas expressed in student drawings about the location of tectonic plates. The question that prompted in-service educators to respond was “where are tectonic plates located?” Instructions during interviews with undergraduates’ were “construct a drawing including a person (yourself),

Figure 3: Student ideas about the geographic location of large, frequently occurring earthquakes in North America. Each student completed a map as shown in figure 1. Earthquake locations were pooled from entire study population to produce this map of
a tectonic plate and Earth’s surface, including labels” and “describe the drawing.”

Drawing Analysis

Drawings designed to elicit ideas about the spatial relationship between Earth’s surface and tectonic plates were categorized based upon consistency between a verbal response (interview) and student drawing of interior Earth. As described previously, undergraduates’ were asked to construct a drawing that included Earth’s surface, a person and a tectonic plate. The drawing was placed in a representative category, according to where a student placed a tectonic plate relative to Earth’s surface. Five dominant categories were identified (Figure 4) into which all collected drawings could be placed.

Using the drawing categorization along with demographic information associated with each drawing collected, a $\chi^2$-test of independence was completed to determine whether gender was independent of where the student placed a tectonic plate. Undergraduate age ranged from 17-25. To achieve the best dispersion of ages, a bin was created for each year (i.e. bin 1 = age 17, bin 2 = age 18, ect.) Unfortunately, it was discovered there was not a broad enough distribution of ages in the undergraduate population and not a broad enough range of responses in the in-service population to create valid results.

Map Analysis

Completed maps were scanned electronically and imported into ESRI’s ArcMap 9.1 as a .TIFF file. Each map was geo-referenced to a scaled, Robinson-projected map and rectified with a cell size of 750 meters. Each feature/phenomena marked on an individual map was then transferred from the electronic scan of the student map to a
Figure 4: Representative undergraduate representations of tectonic plate locations by category. Category 1) Surface of tectonic plate is Earth’s surface, Category 2) Tectonic plate lies directly under a layer of Earth labeled ‘crust’, ‘lithosphere’, or ‘surface’. Top of plate and bottom of labeled layer must be in contact, Category 3) Tectonic plate lies just below (almost touching) a layer of Earth labeled ‘crust’, ‘lithosphere’, or ‘surface’, Category 4) Tectonic plate lies deep within Earth. Closer to center than surface, and Category 5) Other theories. Example: Interior Earth has been stratified in horizontal layers including a tectonic plate.
shape file. This result of this process was a point pattern of student conceptions of large, frequently occurring earthquake events in North America (Figure 3).

Creation of a point pattern requires that data meet several criteria. According to O’Sullivan and Unwin (2003), requirements or restrictive assumptions for a set of events to constitute a point pattern include: 1) the pattern must be mapped on a plane; 2) the study area should be determined objectively with non-arbitrary boundaries; 3) all relevant entities in the study are should be included; 4) there should be a one-to-one correspondence between objects in the study area and events in the pattern; and 5) the event locations must be proper and should not be chosen as a representative or be arbitrary points on a line. While student earthquake data met these criteria, volcano and mountain data did not. As a result, data analysis was limited to earthquake data.

Point pattern analysis completed on earthquake data included average nearest neighbor, kernel density, and directional distribution calculations. Completed point pattern analysis will provide insight to whether undergraduate students were able to produce an earthquake event pattern comparable to actual earthquake events. Average nearest neighbor distance calculations will determine if events are clustered or dispersed randomly across the projected area. Kernel density calculations will determine if events are clustered and provide areas of increased clustering. Standard directional analysis will result in directional trend ellipses which allow a comparison of the directional trend of student vs. actual earthquake events.

The average nearest neighbor distance is the distance between each earthquake event and its nearest earthquake event. Using this distance, averages of nearest neighbor distances are then calculated. If the average distance of the earthquake distribution
(observed) is less than the average for an expected earthquake event distribution (expected), the distribution of earthquake events are considered to be clustered. If the average observed distance is greater than an expected distance, the features are considered to be randomly dispersed. Another measure of event clustering is the average nearest neighbor index. The average nearest neighbor index is expressed as the ratio of the observed distance divided by the expected distance. The expected distance is based upon a hypothetical random distribution with the same number of features covering the same total, projected area. Using the nearest neighbor ratio, it can be determined if the pattern exhibits clustering. If the ratio is less than or equal to one, the pattern exhibits clustering. If the index is greater than one, the event trend is considered dispersed.

Kernel density was calculated to determine the density of earthquake events in a search radius around each event. The output of kernel density calculations produced a contoured surface map of earthquake events (Figure 6). The surface value is highest at the location of the event, diminishing with increasing distance from the event, reaching zero at the maximum limit of the search radius distance from the point.

Standard direction is a variation of standard distance analysis that examines directional trends around the mean center of data, encircling data within one, two and three standard deviations. This statistical test was completed to determine the directional trend of the student data compared to actual earthquake data.

Results

Educator and undergraduate ideas about tectonic plates, earthquakes, and mountains were identified. Undergraduate responses to questions such as ‘what is a mountain?’, ‘what is an earthquake?’, and ‘where are tectonic plates located?’ were very
similarly to those of the in-service population (Tables 2, 3, & 5). Responses collected from undergraduates included verbal and diagrammatic responses while in-service educators were limited to written responses only. Collected data from both populations were coded and categorized with regards to participant ideas. The same criteria were used when coding descriptions of tectonic plates, earthquakes and mountains for both populations.

_Tectonic Plate Location_

**Undergraduate Students**

39 interviews were completed but only 37 drawings of tectonic plate location were collected from undergraduate students. Two interviewees did not create a drawing. Using student drawings of tectonic plate location, five mental models of tectonic plate location were identified (Figure 4) ranging in correctness from most correct (category 1) to least correct (category 5). Students with the most correct mental model of tectonic plate location (category 1; n = 13) have described the surface of Earth as the surface of a tectonic plate or a tectonic plate as the lithosphere “…as long as you’re standing on some type of soil, you are on the plate…” or “…I guess the whole Earth is covered in different plates and no matter where you’re at you’re on a plate…” Students who created a category two drawing (n = 11) described tectonic plates lying directly under a layer of Earth labeled ‘crust’, ‘lithosphere’, or ‘surface’. Typical responses from a student whose model fit into category 2 may include explanations such as “…the plate would be just underneath the dirt and grass and Earth’s surface...about 200 yards” or “…I think there is probably something in-between the surface and the plate…” Students who created a category three drawing (n = 5) described tectonic plates lying just below a layer of Earth
labeled ‘crust’, ‘lithosphere’, or ‘surface’ but not in contact with that layer. A category 3 response may include statements such as “…since the crust is solid, they [plates] can’t be part of the crust so that means that maybe something that lies underneath the crust and upper mantle…” or “…it’s [plate] like really close to the surface, maybe not touching it, but pretty close…” Students who created a category four drawing (n = 4) described tectonic plates as lying deep within Earth, closer to center than surface. Category four responses may include statements such as “…Q: How far would I have to dig to see one [plate]? I: Pretty far…ten thousand feet...” Students who created a category five drawing(n = 4) described tectonic plates as being horizontally stratified within the Earth or shaped like pieces of pie with the core at the center and outer edge at the surface. Category 5 responses may include statements such as “…no I think they’re [plates] pretty far deep in the Earth...like billions of miles...” Digitally enhanced student drawings and descriptions of each category are shown in Figure 4.

In-service Educators

Written responses from 110 in-service educators about the location of tectonic plates were collected via questionnaires. Three mental models of plate location were identified from the in-service population ranging from most correct (category 1) to least correct (category 3). Educators provided written responses that were placed in categories one, two and three only. Without drawings to compare with questionnaire responses, the in-service coding was limited to written descriptions. Educators with the most correct ideas of plate location (category 1) have described the surface of Earth as the surface of tectonic plates or a tectonic plate as the lithosphere or crust (n = 87) “…all of the Earth’s surface is part of one of the tectonic plates. So, you can look down and see the one you
are on...” Educators whose ideas of plate location was placed in category two described tectonic plates lying directly under a layer of Earth labeled ‘crust’, ‘lithosphere’, or ‘surface’ (n = 18) “…under the surface of the planet floating on the molten mantle...” Descriptions placed in category three were also given by educators and described tectonic plates just below a layer of Earth labeled ‘crust’, ‘lithosphere’, or ‘surface’ but not in contact with that layer (n = 4) “…plates are found between the crust and the top part of the mantle...” The other 3% did not respond to the question in a way that defined the plate/surface relationship or did not provide a response. Responses that were not categorized included “…on terrestrial planets that have a hard surface and a part liquid interior...” or “…scientist can detect them by watching the sideways motion of the land...”

Mountains

Undergraduates Students

Undergraduate students responded to the question ‘what is a mountain?’ (Table 2) and ‘how are mountains formed?’ (Table 3) Dominantly occurring themes among undergraduates regarding the question ‘what is a mountain?’ (Table 2) included 1) big/tall rocks, piles of Earth, and a large landmass (69%), 2) crunched up tectonic plates (18%), 3) rocks pushed up from below the surface (3%) and volcanoes (3%). Dominant ideas about mountain formation in the undergraduate population (Table 3) included 1) plate collision/motion, tectonic plates, and compression (69%), 2) glaciers and sediment buildup (8%), and 3) deformation of rocks due to faulting and folding (5%) and volcanism (5%).
In-service Educators

In-service educators also responded to the questions ‘what is a mountain?’ and ‘how are mountains formed?’ Dominant themes among in-service educators when asked to define a ‘mountain’ (Table 2) included 1) a landmass elevated above sea-level or surroundings (65%), 2) elevated or uplifted crust (19%), and 3) a big pile of rocks (9%). Dominant ideas about mountain formation (Table 3) included 1) convergence, collision and/or subduction of tectonic plates (68%), 2) volcanism, hotspots, and/or intrusions (52%), and 3) deformation of the tectonic plates or Earth’s crust including folding and faulting (29%).

**Table 2: What is a Mountain?**

<table>
<thead>
<tr>
<th>What is a mountain?</th>
<th>In-service %</th>
<th>Undergraduate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>landmass elevated above sealevel/surroundings</td>
<td>65</td>
<td>0</td>
</tr>
<tr>
<td>big/tall rocks, pile of earth, large landmass</td>
<td>9</td>
<td>69</td>
</tr>
<tr>
<td>elevated or uplifted crust</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>cruched up tectonic plates</td>
<td>2</td>
<td>18</td>
</tr>
</tbody>
</table>

**Table 3: How are Mountains Formed?**

<table>
<thead>
<tr>
<th>How are mountains formed?</th>
<th>In-service %</th>
<th>Undergraduate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>plate convergence/collision/subduction</td>
<td>68</td>
<td>69</td>
</tr>
<tr>
<td>volcanism, hotspots, intrusion</td>
<td>52</td>
<td>5</td>
</tr>
<tr>
<td>deformation of tectonic plates or crust</td>
<td>29</td>
<td>5</td>
</tr>
<tr>
<td>glaciers and sediment buildup</td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>
Earthquakes

Undergraduate Students

Undergraduate students were asked to provide an explanation or definition of an earthquake (Table 5). Additionally, students were also asked to express their ideas of where large, frequently occurring earthquakes occur across the globe by placing a mark on a blank world maps (Figure 1). Dominant themes among students when asked ‘what is an earthquake?’ (Table 5) included 1) plate collision, movement or shift (46%), 2) a release of energy (10%) and 3) a shaking or movement of the ground (10%). Student ideas about earthquake event locations were transferred from paper maps to ArcMap 9.1 (Figure 3). One-third of student earthquake events were concentrated in North America and the remaining two thirds were scattered across the globe. To achieve more local results, data analysis was first constrained to the boundaries of North America (Canada, United States, and Mexico). Once global data was narrowed to North America events only, it was apparent that a significant amount of the North American data lies in California. Our attention was then focused to the state of California and a small off-shore region for data analysis.

Table 4: Average Nearest Neighbor Calculations

<table>
<thead>
<tr>
<th></th>
<th>Average Nearest Neighbor Calculations (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed Earthquake Events (USGS)</strong></td>
<td></td>
</tr>
<tr>
<td>observed</td>
<td>0.3014</td>
</tr>
<tr>
<td>expected</td>
<td>105520</td>
</tr>
<tr>
<td>ratio</td>
<td>$3 \times 10^{-6}$</td>
</tr>
<tr>
<td><strong>Student Earthquake Events (Maps)</strong></td>
<td></td>
</tr>
<tr>
<td>observed</td>
<td>84201</td>
</tr>
<tr>
<td>expected</td>
<td>72629</td>
</tr>
<tr>
<td>ratio</td>
<td>1.159</td>
</tr>
</tbody>
</table>
Nearest neighbor calculations for student earthquakes in California and a small off-shore area in the Pacific indicated that student earthquake events are not clustered but rather, dispersed. Nearest neighbor calculations for observed earthquake events (USGS) also indicate clustering. Nearest Neighbor ratio values of a point pattern less than or equal to one indicate clustering. The ratio of student earthquakes is greater than one indicating a dispersed pattern whereas the observed earthquakes ratio is less than one indicating clustering.

After observed earthquake events and student earthquake events were projected (Figure 6a), it was possible to analyze and compare observed vs. student earthquake events. The goal of this analysis was to determine where events were clustered within the earthquake point patterns (Figure 5) and to compare the directional trend of student and observed earthquake events using standard directional ellipses (Figure 6b). Cluster analysis was completed using kernel density calculations. Kernel density calculates the density of events in a search radius around each event. In this case, the search radius around each earthquake event was one square kilometer. The output of kernel density calculations produced a contoured surface map of earthquake events (Figure 5). Using the density maps, the locations of event clustering of student and observed earthquakes were compared. The offshore area was created to ensure that all observed along the coast
Figure 5: A) (left) Kernel density of student earthquakes in California and offshore. It is evident that student earthquake events are highly clustered along the entire coast and towards the eastern and northern boundaries. B) (right) Kernel density of observed (USGS) earthquakes in California and offshore. Observed earthquakes also show clustering along the coast, but in at lower values. It is very evident that the observed earthquakes are more densely clustered off the northern shore or California.

of California were included in the analysis. To ensure that calculated values (i.e. average nearest neighbor, kernel density) for student and observed earthquake events were commensurable, equal polygonal areas were used (Area of California and offshore polygon = 437854 Km$^2$). It is evident that student earthquake events (Figure 5a) are clustered along the coast of California and along the northern and eastern boundaries. Also, students have created multiple areas of high clustering throughout the central portion of California. Observed earthquakes (Figure 5b) are also clustered in California; although not as many highly clustered areas exist when compared to student earthquake events. Even though there are a significantly greater number of observed earthquake events in California and offshore than student earthquake events, the locations of highly
clustered areas of observed earthquakes differs greatly when compared to areas of highly clustered student earthquake events.

Completed directional trend analysis was also completed, which shows directional trends within the point pattern of earthquake events. Trend analysis allowed for comparison of the directional trend of student earthquake data to observed earthquake data in the area. The result of this analysis indicates that the student earthquake trend varies from the observed earthquake trend (Figure 6). However, comparison of the student earthquake trend with the actual earthquake trend indicates that the undergraduate participants are familiar with the idea that earthquakes occur frequently on the West Coast of North America and specifically California.

_In-service Educators_

In-service educators were asked to provide an explanation or definition of an earthquake. Dominant themes among educators when asked ‘what is an earthquake?’ (Table 5) were very similar to those of undergraduate students and included 1) plate collision, movement or shift (72%), 2) a release of energy (16%) and 3) a shaking or movement of the ground (11%). Educators were not asked to create maps of large, frequently occurring earthquakes because of the data collection method which limited educators to written responses only.

_Tectonic Plate Placement vs. Gender_

Demographic data was collected from both populations to allow a $\chi^2$-test of independence of demographic information vs. plate location to be completed. Of the collected demographics (i.e. age, gender, high school location), gender was the only
Table 5: What is an Earthquake?

<table>
<thead>
<tr>
<th>What is an Earthquake?</th>
<th>In-service</th>
<th>Undergraduate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate collision, movement/shift</td>
<td>72%</td>
<td>46%</td>
</tr>
<tr>
<td>A release of energy/pressure</td>
<td>16%</td>
<td>10%</td>
</tr>
<tr>
<td>Shaking/movement of the ground</td>
<td>11%</td>
<td>10%</td>
</tr>
</tbody>
</table>

variable chosen that allowed for a valid $\chi^2$-test of independence to be completed by both populations. If gender dependency was discovered in either population, determining which gender held more correct mental models of plate location was to be done using a scoring system entitled ‘the gender score’. The gender score was created to assign a score to each gender based upon tectonic plate placement. The gender score is based upon total number of drawings, by each gender, that were placed into each category and the number of study participants. The score is assigned to each gender by taking the quantity of the sum of the scores per gender and multiplying by the category number then dividing that quantity by the number of participants per gender in the study population.
Figure 6:  A) (left) Student ideas about the geographic location of large, frequently occurring earthquakes projected along with observed earthquakes (USGS) from 2000-2006, magnitude 5+.  B) (right) Directional trend analysis comparing the directional trend of student earthquake events vs. observed earthquake events.

For example, if in a study with ten male and ten female participants, seven males produced a drawing fitting into category one, the male score for category one is 0.07. If six females produced a drawing fitting category one, the female score for category is was 0.06. The gender with the lowest score, in this case, has expressed mental models of

**Table 6: Example of Gender Score**

<table>
<thead>
<tr>
<th>Category</th>
<th>Male</th>
<th>Female</th>
<th>$M_s$</th>
<th>$F_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>6</td>
<td>Gender (7) x Category (1) n (10)</td>
<td>Gender (6) x Category (1) n (10)</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>6</td>
<td>0.07</td>
<td>0.06</td>
</tr>
</tbody>
</table>
plate location that are more correct with respect to the entire study population (Table 6).

**Undergraduate Students**

Demographic information collected from undergraduate students prior to each interview was compared to tectonic plate location (categories 1-5) via a $\chi^2$-test of independence. Critical values of $\chi^2$ were calculated at $\alpha=0.05$ level of significance with the null hypothesis stating that placement of tectonic plates is independent of gender. When comparing undergraduate student gender vs. plate location, the null hypothesis was rejected ($\chi^2$-critical; $\alpha = 0.05 = 9.49$; $\chi^2$-calculated = 27.02), suggesting that placement of tectonic plates is dependent on gender (Appendix E).

**In-service Educators**

Demographic information collected from in-service educators via questionnaires was compared to tectonic plate location (categories 1-3) via a $\chi^2$-test of independence. The null hypothesis was also rejected for the in-service population with respects to gender vs. plate location ($\chi^2$-critical; $\alpha = 0.05 = 5.99$; $\chi^2$-calculated = 56.34), suggesting that plate location is dependent on gender (Appendix E).

**The Gender Score**

Once gender dependency was discovered in both populations, we were interested in which gender held more correct mental models of plate location. Assigning a score to each gender, the gender score, based upon tectonic plate placement (Table 7) indicated that males from both populations hold a more correct model of tectonic plate location than females. Descriptions of plate locations were fairly consistent across genders when describing plate locations, although males were able to produce more correct drawings (undergraduates) or descriptions (educators). Since five categories were created with
respect to student drawings and three with respect to educator descriptions of tectonic plate location, a gender score exists for each category.

### Table 7: Gender Score

<table>
<thead>
<tr>
<th>Category</th>
<th>Educator Score</th>
<th>Undergraduate Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>1</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

### Discussions

Collected data provides insight into the mental tectonic models held by in-service educators from across the United States and undergraduate students enrolled in introductory geology. Interview text, along with collected drawings, allowed for examination of ideas held by undergraduates and questionnaire responses from in-service educators provide a glimpse into ideas held by science educators. These data sets together have allowed us to examine and compare mental tectonic models held by both populations.

As previously mentioned, multiple theories have arisen to explain why children and adults encounter difficulty understanding plate tectonic theory. The American Association for the Advancement of Science (AAAS, 1993) envisions that every student who participated in this study should have been exposed to plate tectonic concepts while in grade school (K-12) and should have an understanding of certain tectonic concepts such as the cause of earthquakes, mountains and the solid crust of the Earth. This includes understanding that the crust of the Earth is composed of tectonic plates that
move, creating divergent, convergent, and transform plate boundaries. Despite the attention paid to plate tectonics instruction, models of plate tectonics and driving mechanisms of tectonics and related phenomena presented by students and K-12 educators may often differ from those ideas that are accepted scientifically (Gobert, 2000; Libarkin et al., 2005, Marques & Thompson, 1997). As supported by Vosniadou and Brewer (1994), it is suspected that “initial models” of how landscapes form (i.e. mountains) and phenomena occur (i.e. earthquakes, volcanic eruptions) are likely to have formed at an early age. Over time and instruction mental models will slowly migrate towards a more scientifically accepted model. Gobert (2000) states that conversing about mental models allows for model refinement, which may provide aid to students while migrating towards more scientifically accepted models. However, all conceptions do not undergo change with development, unlike the original model of conceptual change described by early conceptions researchers, but will continue to be entertained into adulthood if not reconstructed (Spelke, 1991). According to Thagard (1992), conceptual change may involve the addition, transformation, and/or deletion of concepts where transformations of concepts from one concept to another are termed “branch jumping”. Chi (1992) describes a similar model of conceptual change to Thagard’s “branch jumping” except the concepts are jumping from one ontological category to another.

Mountains and Mountain Formation

Undergraduates and educators provided very similar responses to the question ‘What is a mountain?’ (Table 2). Typically, educators were able to provide a more detailed explanation and provide multiple mechanisms for mountain formation whereas undergraduates were not able to provide as much detail. Educator responses to the
question “what is a mountain?” allowed us to make a general comparison about the use of material relating to tectonics in the classroom and the correctness of teacher ideas. Generally speaking, those educators who include discussions of plate tectonics in their daily instruction or as a significant amount of their curriculum were able to properly use technical language more correctly and provide more accurate descriptions than those who do not. For example, those whose curriculum included the majority (80 - 100%) of topics covered by the questionnaire (Appendix D), provided responses such as the following when asked to define a mountain and describe mountain formation: “...a mountain is a geological and geographical high point that stands out in the terrain...[mountain formation] by the collision of tectonic plates or volcanism. [Formation by Volcanism] occurs when an oceanic plate is subducted under a continental plate...” Educators who do not incorporate plate tectonics in their curriculum provided responses similar to the following “...[defining mountain] an elevated landform with a wide base and a peak at the top...[mountain formation] by glacial gouging, glacial deposition, volcanic eruption, by the compression and lifting of tectonic plates...” Not surprisingly, these data indicate that those educators who teach many tectonics concepts in their classrooms were able to provide more specific and more accurate explanations of tectonic phenomena. In contrast to in-service educators, the use of technical scientific language by undergraduates did not correlate to the correctness of their explanations of tectonic phenomena. Certainly, in-service educators, especially those who teach plate tectonics, should have a higher level of understanding than undergraduates in an introductory geology course
Earthquakes

Undergraduates and educators provided very similar responses when asked to define and earthquake (Table 5). Unlike when asked to define mountains and describe mountain formation, undergraduates were able to provide explanations that compared equally to educators. The three dominant categories identified from both populations consisted of 1) plate collision, movement or shift; 2) a release of energy or pressure; and 3) shaking or movement of the ground. The most scientific ideas presented for the definition of an earthquake was a release of energy or pressure. However, 84% of the educators and 56% of the undergraduates involved in this study did not define an earthquake as a release of energy or pressure. For this reason, we can assume that a significant number of educators are describing earthquakes to students as a shaking of the ground and/or a plate collision, movement or shift. The problem with describing earthquakes as a shaking of the ground is that other things cause the ground to shake that are not earthquakes. It is true that occasionally, the ground shakes enough to be detected by human beings when an earthquake occurs. However, this is not always true, therefore, an earthquake cannot be defined as a shaking of the ground. It is also assumed that when a definition of an earthquake is provided, it is described in terms of how earthquakes affect human beings, not what the term earthquake actually means.

Further analysis of student earthquake maps, average nearest neighbor calculations, and kernel density maps has provided evidence that students possess knowledge of where earthquakes generally occur in North America but are either 1) not familiar with West Coast geography and/or 2) not able to provide a mechanism for earthquake activity. Since all of the undergraduate participants involved in this study
were from the East Coast (primarily the Ohio Valley area), an understanding of the local geography of the West Coast was most likely lacking. Students living on the West Coast or students who are explicitly taught about West Coast geography and geology may have a better understanding earthquake location, especially if they were able to associate earthquake events with certain geographical locations (i.e. cities, states, political boundaries) or geologic features (i.e. fault lines, mountains, volcanoes). Additionally, undergraduates might be able to produce a more accurate, clustered event pattern if the driving forces of earthquakes were better understood. Evidence from kernel density maps suggest that undergraduate students do not have a clear understanding of the mechanisms causing earthquakes to occur in California or surrounding areas. Exposure to actual earthquake location maps coupled with instruction about major earthquake producing faults in North America may impact student placement of large earthquake events. Nonetheless, the student earthquake data does show that even though students may not possess a thorough understanding of West Coast geography or the driving mechanism behind earthquakes, they were able to place earthquakes in the general areas where they do happen frequently. This indicates that undergraduates have a general understanding of continental United States geography and earthquake occurrence, but are not perhaps as familiar with areas in which they are not residents.

Gender vs. Plate Locations

As explained previously, the gender score was devised in an attempt to understand the relationship between gender and tectonic plate models. This score provides a quantitative evaluation of the correctness of mental models of tectonic plate location held by each sub-group, with a lower score correlating to a more correct model.
Although males and females both held ideas not embraced by the scientific community, males tended to, as a group, hold a more correct idea. The scope of this study was not focused on gender biases in science education by any means, but it is interesting to consider. Numbers of responses per category were very similar when comparing males to females but the gender scores were significantly different. This can be attributed to the fact that females held more ideas that were placed in categories three, four and five. Referring back to Table 7, overall, males, both undergraduates and educators contributed fewer responses that were placed in higher-level, and thus higher scoring, categories. This suggests that gender bias may exist with respect to the sophistication of tectonic models.

Conclusions and Implications

The idea of collecting information concerning plate tectonics from undergraduates and in-service educators initially was to compare the ideas held by both populations and to try to understand if ideas may be being passed from educator to student. This study provides evidence that undergraduate students and in-service educators hold alternative conceptions regarding the very basics of plate tectonic theory and the mechanism associated with plate tectonics including mountain formation, the cause of earthquakes, and tectonic plate location. It is evident that ideas held by undergraduate students (46% pre-service educators) in this study may not be gravitating towards more correct ideas but are rather carried into adulthood or even into the K-16 classroom. For example, when comparing undergraduate and educator ideas of plate location, it is evident that non-scientific ideas are becoming more scientific while en route from undergraduate student or pre-service educator to in-service educator. However, all non-scientific ideas are not
being resolved as a normal course of maturation and instruction. Non-scientific ideas about plate tectonics need to be resolved at the undergraduate level in introductory geology courses or during K-12 instruction in order for this cycle of alternative, non-scientific conceptions to be broken.

Ideas about plate tectonics are presented to children as early as the third grade and continue to be presented throughout the K-12 program (AAAS, 1993; ODE, 2003). Further learning about tectonics may continue as an undergraduate student and those undergraduates, as is true for some students in this study, may go on to become science educators. If models presented to children as early as the third grade contain non-scientific ideas about plate tectonics or are not explained thoroughly and are continually presented to young adults throughout a K-12 program, undergraduates will continue to hold non-scientific ideas about tectonics. Effective presentation of tectonic models may require instruction that promotes student interaction and engagement in their own learning in addition to traditional lecture and readings. Evidence exists for the use of drawings as an effective tool for gauging student ideas about tectonics (Gobert & Clement, 1999). Additionally, Johnson and Reynolds (2004) promote the use of student drawings not only as an assessment tool, but also as a learning tool to promote active learning by increasing student involvement in the classroom. They report that using student drawings “engages students in the learning process, develops critical thinking skills, teaches communication skills, and makes courses more enjoyable (p. 47).” Our study supports the notion that drawings are a valuable learning tool. We found that students were able to demonstrate understanding regarding the location of tectonic plates but when asked to represent this information diagrammatically, the majority (65%) were
unable to produce a correct model. Although many students were able to use terms such as lithosphere, asthenosphere, and crust when describing the location of a plate, many drew the lithosphere deep inside the Earth or described the crust as only the hard outer shell we stand on with no direct relationship to tectonic plates.

Further research is needed regarding in-service educator mental tectonic models and what models and/or ideas are being passed on to students. Again, this study was not specifically designed to express specific ideas that are or may passed to students, but to identify and compare mental tectonic models of undergraduate students and in-service educators. However, similar ideas, both scientific and non-scientific, were observed in both populations which suggest that ideas about tectonics are learned at a young age and may never become scientifically acceptable ideas, despite a decade or more of instruction.
References


The amendment, detailed below, and submitted for the following research study has been approved by the Institutional Review Board at Ohio University. Approval date of this amendment does not affect the expiration date of the original approval.

Amendment: Recruitment of additional students; Recruitment of science educators

Project: Geoscience Concept Test: Questionnaires, Interviews and Piloting

Project Director: Julie Libarkin

Advisor: (if applicable)

Department: Geological Sciences

Rebecca G. Cale
Institutional Review Board

3/30/05
Date
Appendix B: Interview Protocol

I. Mountains (primarily concerned with N&S America)

1. What is a mountain?
How are mountains formed?
What causes mountains to be formed?

2. Where can we go to see mountains?

On World Map:

1. Draw where we might go to see mountains.
Anticipated Probe: Why have you drawn mountains here but not here?

2. Have mountains always been there?
Anticipated Probe: What evidence might we have that suggests that may have not always been there?

II. Earthquakes (primarily concerned with N&S America)

1. Describe what you think an earthquake is?
Do earthquakes cause damage?
Anticipated Probe: If I wanted you to tell me how large or small an earthquake was, how would I do that?

2. Where do large earthquakes usually occur?
Anticipated Probe: Why do earthquakes occur in this particular area?

3. How often do earthquakes happen?

3. What causes earthquakes?

On World Map

4. Place an x in any location where you think large frequent earthquakes happen.
Anticipated probe: Why do earthquakes happen there?
5. Is there a specific earthquake event you remember that you could tell me about? Where did it happen?

III. Tectonic Plates

1. What is a tectonic plate?

Where are plates located?

2. How do geologists know anything about tectonic plates?

Anticipated probe: is there anyplace we can see a tectonic plate?

3. Is there more than one plate?

Anticipated probe: how do we know that there are multiple plates? How do we know that there is only one plate?

4. Do these plate move?

Anticipated probe: is there any evidence to suggest that they move?

On Blank Paper


Anticipated probes: where are you located in relation to the tectonic plate? How deep are tectonic plates below the surface? Do the continents move independently of plates or do they move with the plates? What is on a plate?

Appendix A: Interview Protocol

IV. Plate Boundaries

1. Is there anyplace on earth where rock is formed?

2. Is there anyplace on earth where rock is destroyed?
Appendix C: IRB Consent Form

Title of Research: Geoscience Concept Test: Interviews
Principal Investigator: Marcus Wunderle
Department: Geological Sciences

Federal and university regulations require signed consent for participation in research involving human subjects. After reading the statements below, please indicate your consent by signing this form.

Explanation of Study

Purpose: To study student ideas about the Earth.

Procedures: Subjects will complete a demographic questionnaire and a brief questionnaire about the Earth. Subject will be asked questions about the Earth. Interview will be audio taped. Interviews may be video taped with participants consent.

Duration of subject's participation: Interviews will last between one half and one hour.

Risks and Discomforts: There are no known risks of this research.

Benefits: There are no known benefits of this research to the participants. This research may lead to improved teaching in entry-level Earth Science courses in the future, and could further our understanding of the relationship between teaching and learning in science.

Confidentiality and Records: Numbers, rather than names, will be used in the transcription of interviews and in all written materials and presentations. Audiotapes and/or videotapes will be accessible to the Principal Investigator, interviewer if not the Principal Investigator, transcriber, and other project personnel (after the close of the Fall quarter) only. Audiotapes will be erased after transcription, no later than one year after the interview takes place.

Compensation: Participants enrolled in GEOL 101 during Fall 2004 will receive 20 extra-credit points. Participants will not be otherwise compensated for their participation.

Contact Information
If you have any questions regarding this study, please contact Marcus Wunderle, mw111899@ohiou.edu. If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

I certify that I have read and understand this consent form and agree to participate as a subject in the research described. I agree that known risks to me have been explained to my satisfaction and I understand that no compensation is available from Ohio University and its employees for any injury resulting from my participation in this research. I certify
that I am 18 years of age or older. My participation in this research is given voluntarily. I understand that I may discontinue participation at any time without penalty or loss of any benefits to which I may otherwise be entitled. I certify that I have been given a copy of this consent form to take with me.

Signature_________________________________________________ Date ______

Printed Name______________________________________________

I give consent for the following:

☐ The video recording of this interview for research purposes and/or scholarly presentations only.
☐ The use of digital photography to be used before, during, and after this interview for research purposes and/or scholarly presentations only.

Initial ___________ Date ___________
Appendix D: In-service Educator Questionnaire

Fellow Science Educators:

I am asking for participation in a research study that I am currently conducting for completion of my master's thesis. I am investigating teacher ideas about the Earth. Please take a few minutes and fill out the questionnaire below. I also ask that you do not refer to any textbooks or related references while completing the questionnaire. Completion of this questionnaire means you have given consent for any collected materials to be used in professional publications and/or scholarly presentations. For a printable consent form, see attachment.

Age:
Gender:
Race/Ethnicity:
Years of Teaching Experience:
Grades Taught:
State:
Current Subject(s) Taught:

Please answer all questions to the best of your ability and be as descriptive as possible. Imagine that you are explaining each answer to students who have never encountered this material before.

1. a) What is a mountain?

   b) How are mountains formed?

2. If you had to explain what an earthquake was and what caused them to your class, what would you say?

3 a) What are tectonic plates made out of?

   b) Where would you find a tectonic plate?

4. How much of the above content is included in your classroom curriculum?

5. Thank you for your participation!! If you have any questions or comments about the study, put them here and I will respond. Please be sure that you have "replied to sender" only (mw111899@ohiou.edu), not the entire NSTA community!
# Appendix E: $\chi^2$-Test of Independence

## Table of drawing categorization by gender for $\chi^2$-test (undergraduates)

<table>
<thead>
<tr>
<th>category</th>
<th>male</th>
<th>female</th>
<th>row totals</th>
<th>degrees freedom</th>
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<td>6</td>
<td>13</td>
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<tr>
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<td>74 = N</td>
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</tbody>
</table>

## Table of $\chi^2$ calculations for gender vs. plate location (undergraduates)

| category | observed (O) | expected (E) | $|O - E|$ | $(O-E)^2$ | $\chi^2$ calculated |
|----------|--------------|--------------|----------|-----------|--------------------|
| cat1/M   | 7            | 2.99         | 4.01     | 16.11     | 5.39               |
| cat1/F   | 6            | 3.51         | 2.49     | 6.18      | 1.76               |
| cat2/M   | 5            | 2.53         | 2.47     | 6.12      | 2.42               |
| cat2/F   | 6            | 2.97         | 3.03     | 9.16      | 3.08               |
| cat3/M   | 2            | 1.15         | 0.85     | 0.72      | 0.63               |
| cat3/F   | 3            | 1.35         | 1.65     | 2.72      | 2.01               |
| cat4/M   | 3            | 0.92         | 2.08     | 4.33      | 4.71               |
| cat4/F   | 1            | 1.08         | 0.08     | 0.01      | 0.01               |
| cat5/M   | 0            | 0.92         | 0.92     | 0.84      | 0.92               |
| cat5/F   | 4            | 1.08         | 2.92     | 8.52      | 7.88               |

## Table of $\chi^2$ critical and calculated values (undergraduates)

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<th>9.49</th>
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<td>0.01</td>
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<tr>
<td>deg. freedom</td>
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<td>4</td>
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<tr>
<td>$\chi^2$ calculated</td>
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<td></td>
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</table>
Appendix E: continued from previous page

Table of description categorization by gender for $\chi^2$ test

\[
\begin{array}{c|cc|c|c}
\text{category} & \text{male} & \text{female} & \text{row totals} & \text{degrees of freedom} \\
1 & 37 & 45 & 82 & 2 \\
2 & 3 & 9 & 12 & \\
3 & 0 & 3 & 3 & \\
\hline
\text{column totals} & 40 & 57 & 194 = N & \\
\end{array}
\]

Table of $\chi^2$ calculations for gender vs. plate location

\[
\begin{array}{l|c|c|c|c|c|c}
\text{category} & \text{observed (O)} & \text{expected (E)} & |O - E| & (O-E)^2 & (O-E)^2 \\
\hline
cat1/M & 37 & 16.91 & 20.09 & 403.72 & 23.88 \\
cat1/F & 45 & 24.09 & 20.91 & 437.11 & 18.14 \\
cat2/M & 3 & 2.47 & 0.53 & 0.28 & 0.11 \\
cat2/F & 9 & 3.53 & 5.47 & 29.97 & 8.50 \\
cat3/M & 0 & 0.62 & 0.62 & 0.38 & 0.62 \\
cat3/F & 3 & 0.88 & 2.12 & 4.49 & 5.09 \\
\hline
\end{array}
\]

Table of $\chi^2$ critical and calculated values

\[
\begin{array}{l|c|c|c}
\text{\(\chi^2\) critical} & 13.28 & 9.21 & 5.99 \\
\alpha & 0.001 & 0.01 & 0.05 \\
\text{deg. freedom} & 2 & 2 & 2 \\
\text{\(\chi^2\) calculated} & 56.34 & \\
\end{array}
\]