Development Of The EGGS *Exam Of GeoloGy Standards* To Measure Students' Understanding Of Common Geology Concepts

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ABSTRACT

Geoscience education researchers have considerable need for criterion-referenced, easy-to-administer, easy-to-score, conceptual surveys for undergraduates taking introductory science survey courses in order for faculty to monitor the learning impacts of innovative teaching. In response, this study establishes the reliability and validity of a 28-item, multiple-choice, pre- and post- EGGS Exam of GeoloGy Standards. EGGS addresses 11 concepts derived from a systematic analysis of the overlapping ideas from national science education reforms: NGSS, AAAS Benchmarks, Earth Science Literacy Principles, and NRC National Science Education Standards. Leveraging best-practices for creating and field-testing items, EGGS emphasizes natural student language over technical scientific vocabulary, leverages illustrations over students' reading ability, specifically targets students' misconceptions, and covers the range of topics most geology educators expect general education students to know. EGGS is argued to be valid and reliable with college introductory science survey students based on standard measures, including clinical interviews with students and expert review.

Keywords: Geoscience Education Research; Geocognition, Assessment

In a time of international concern and debate about a changing global environment, geoscience educators are broadly interested in improving the teaching and learning of introductory geology survey courses for non-science majors and future teachers at the undergraduate level. Based on our analysis of textbook sales, nearly 800,000 undergraduates enroll in an introductory science survey course covering the Earth and space sciences each year. Reflecting the rapidly widening diversity of students now attending institutions of higher education, nearly half of students who take these courses do so at 2-year community colleges or tribal colleges. Yet, few of the faculty teaching these courses have had substantial formal training in pedagogy or contemporary teaching practices as part of their graduate coursework. For many of their students, a *Geology 101* course often marks the end of many college students' formal education in science. As such, *Geology 101* courses serve as a unique—and perhaps final—forum to highlight the intimate relationships between science, technology, and society for students, many of which will go on to become teachers. Lawrenz (2005) and colleagues report that as many as 40% of students in introductory science survey courses eventually become certified teachers who will serve a critically important role for systemic change in the enterprise of science education.

At the same time more and more educators want to know how much their students learn when using competing teaching strategies. There is considerable interest in finding widely accepted assessment instruments that can be easily used across teaching contexts so that comparisons can be made readily (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014). Like other scientific disciplines, the geoscience education community has long been calling for a comprehensive conceptual survey that effectively and efficiently covers the broad range of topics taught in most introductory geology survey courses. Although several competing geoscience education instruments do exist (*viz.*, Cervato, Rudd, & Wang, 2007; Iverson, Steer, &Manduca, 2012; Libarkin, 2008; Libarkin & Anderson, 2005a), the broader impacts of these efforts have seen limited adoption. This is due in large part to a general lack of broad community consensus about which geology topics should be taught, and which topics should be tested. In other words, the geoscience education community has had trouble finding a pathway to meet a commitment to the mantra, "teach what you test, and test what you teach" (Guffey, Slater, Schleigh, Slater, & Heyer, 2016). If one could ascertain a wide consensus of what geology concepts needed to be taught, then one might be able to create a widely adopted geology assessment instrument.

Much of our state-of-the-art understanding about college-level science teaching and learning has been summarized in the National Research Council's publication, Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering (DBER, 2012). The overarching challenge to the higher education community is that learning and retention in college and university science courses could be enhanced by faculty using empirically validated teaching practices and materials that engage students in active learning (DBER, 2012). The critical need resulting from this NRC committee report is for the community to develop an easy-to-implement, classroom-ready assessment to help college faculty systematically evaluate the impact of various teaching innovations.

Other discipline-based education research fields seemingly have been able to reach a reasonable level of consensus about which topics should be taught. Consider the recent example from the Earth sciences domain of astronomy (Singer, Nielsen, & Schweingruber, 2012; Slater, Slater, Heyer, & Bailey, 2015). A roadmap astronomy education research agenda paper by Adams and Slater (2000) drove a decade's worth of development of single-topic conceptual surveys (e.g., Bailey (2012) and colleagues' *Star Properties Concept Inventory* SPCI, among many others cited by Bailey and Lombardi (2015)), before the broader community decided that what was most needed was a single, comprehensive, easy-to-use, easy-to-score, assessment instrument based in natural student language, as opposed to the vocabulary of scientific-jargon. In response, the *Test Of Astronomy STandards*, hereafter referred to as *TOAST*, was developed by Stephanie Slater (2014) and colleagues. Committing to the test design specification of being comprehensive, but still short enough to be manageable, the team isolated the absolute minimum list of concepts a successful student was expected to know and understand by analyzing national reform documents. The geoscience education community could adopt the process used to develop the TOAST in order to successfully create an easy-to-use, easy-to-score assessment instrument for geology. It is to meet these needs that this article is specifically addressed.

BACKGROUND AND CONTEXT

Several conceptual and knowledge diagnostic inventories exist within the geoscience education community. The most recent effort has been a project widely known as the *Geoscience Literacy Exam*, GLE. There is only limited work on this project published in the scholarly literature as yet, although there is some work exists in the non-refereed grey literature (Geraghty-Ward, Iverson, Steer, & Manduca, 2015; Gosselin, Manduca, Bralower, & Mogk, 2013; Iverson, Steer, & Manduca, 2012; Olson, 2014; Steer, Iverson, & Manduca, 2013; and Steer, 2012). In brief, the GLE consists of 52 multiple choice and 30 essay questions based upon big ideas and grand challenges of Earth systems science identified through the NSF-funded *InTeGrate* project. Because of the relative newness of this project it is difficult to predict the extent to which the GLE will find widespread adoption across the geoscience education community. However, one naturally wonders about the manageability of such a large bank of questions by the typical college professor.

The most well-funded effort to create widely-used assessment instruments to measure student's understanding, including Earth science, is that of the *Misconceptions-Oriented, Standards-based, Assessment Resources for Teachers*, MOSART (2015) project. In terms of Earth science, the MOSART project team carefully created 60 multiple-choice questions aligned with the NRC *National Science Education Standards* (1996), in three grade-level bands, and collected substantial field-test data. With the clear exception of Sadler and colleagues' (2009) widely cited article about the importance of developing an instrument to assess students' knowledge of astronomy and space science, MOSART assessment instruments related to Earth science have made surprisingly little penetration into the scholarly literature. MOSART's lack of widespread adoption and use by faculty is likely due in part to the current difficulty in obtaining the test items as researchers and faculty must go through an online tutorial before being granted access. Additionally, part of the lack of widespread adoption might also be due to too many items existing in the item bank to be practical for most faculty to use in a pre-test and post-test format. Moreover, a cursory view of the instrument's face validity suggests that successfully answering the items requires students to have a relatively high English reading ability as the instrument contains few illustrations and, as a result, suffers from a high chance of inadvertently testing reading comprehension instead of the desired level of Earth sciences conceptual understanding, which is consistent with the written cautionary warnings provided by the developers. In the end, for our purposes, the most compelling reason not to use the MOSART items was because it was aligned with only one of the existing science education reform efforts, the NRC's *National Science Education Standards* (1996) and, as such, did not represent a broad community consensus of all the existing efforts at establishing a coherent set of learning targets for geology.

The largest community effort to date is the *Geoscience Concept Inventory,* GCI (Libarkin, Anderson, Beilfuss, & Boone, 2005b). The overall goal of the GCI was to design an assessment instrument that would be a valid tool for use for all entry-level college students nation-wide, and which could be applied to a wide range of courses covering a variety of topics relevant to the Earth Sciences. However, there are several validity issues concerning the GCI.

The first issue limiting the widespread adoption of the GCI pertains to criterion and content validity of the GCI. According to Field (2013), criterion validity determines if a test reflects a certain set of abilities relevant to the GCI's concepts. Field (2013) defines content validity as "the extent to which a measurement reflects the specific intended domain of the content." Libarken (2005a, 2005b, & 2006) and her colleagues used the largely insufficient approach of grounded theory to determine which geology concepts to include in the GCI.

In the development of the GCI, thousands of hours of student interviews were performed and students also completed questionnaires related to geology concepts. After students' responses and questionnaires were transcribed and coded, students' responses were used to decide which content to include when generating the test items for the GCI, which is an ineffective method to develop test items. According to Johnson and Christensen (2014) in education research there are two accepted ways of determining the range and domain of content for an objective test of this nature, norm-referenced tests (NRT), which compares students to each other, and criterion-referenced tests (CRT), which compare students to a predetermined standard. In K-12 education, teachers are often interested in knowing if their students have learned the standards that were developed by content experts and curriculum developers. An example of a standards document is the *Next Generation Science Standards (NGSS)*. An example of a validated CRT is the widely used Slater's *Test of Astronomy STandards (TOAST)* (2014). All items on the TOAST are aligned with at least three national standards documents (NRC *National Science Education Standards,* AAAS *Benchmarks for Science Literacy,* and Achieve Inc's *Next Generation Science Standards),* which addresses criterion validity. Once the items on the TOAST were aligned to standards, experts in the astronomy community reviewed the assessment to ensure content validity. The use of grounded theory for developing the GCI to determine which geology to include turned out to largely be unsuccessful in addressing content and criterion validity.

The second weakness of the GCI pertains to construct validity, which is usually defined as the extent to which the test may be said to measure a coherent idea, in this case, the disciplinary structure and core concepts of geoscience (Huck, 2013). When analyzing students' responses, it is difficult for researchers to compare assessment results to what is already published about students' conceptual understanding in geology. As suggested earlier, the GCI used grounded theory to identify student misconceptions; however, the resulting problem is that researchers are not be able to compare results from the GCI to previously validated literature in geoscience cognition. A connective, broad review of literature in geology cognition seems to be missing from the development of the GCI, adding to the observed lack of adoption by the community.

The third issue interfering with the GCI's widespread adoption by the community relates to face validity, which is a measure of how representative the assessment is at face value (Huck, 2013). The biggest concern about the GCI are the actual test items and the answer choices. Again, the use of grounded theory to develop test items and answers choices is suspect as a strategy. A few items on the GCI did not include the scientifically accurate answer choice as an option because responses from student interviews were used to create the answer choices. Some questions were later removed after IRT item response theory (e.g., Rasch modeling) analysis was performed on pre- and post-test results (Libarkin, Anderson, Deeds, & Callen, 2006). Results from the GCI showed that many items were considered stable; however, the test items that were removed due to the Rasch analysis were items that did not have a clearly correct answer choice. This was inappropriately attributed to biased "gender and racial discrimination" on those specific questions because of the demographic characteristics of those who answered in particular ways (Libarkin & Anderson, 2005a).

The last challenge faced by the general construction of the GCI is one of face validity. Overall, there are 73 questions on the GCI, which are too many questions according to researchers in assessment development (Boud & Falchikov, 2007). When an assessment has too many questions, the researcher often encounters the issue of students developing test exhaustion and the researcher becomes unsure if students are marking incorrect answers because they don't know the information or if they answer questions incorrectly because they are tired from taking the test. Generally to avoid test exhaustion, a good assessment will include 25 to 35 questions (Downing & Haladyna, 2006).

In regard to the construction of the test items, it is known from expert assessment developers Miller and Linn (2000) that an item should only contain one correct or clearly best answer. There are several questions on the GCI that state, "Select all correct answers that apply." According to Miller and Linn (2000), when an assessment asks students to "select all correct answers" this creates two problems. First, these types of questions are nothing more than a collection of true/false items presented in multiple-choice format. Best practice is that students should be able to answer a question without any given choices; otherwise, such items require a mental response of true or false to each alternative one at a time rather than a comparison and selection of alternatives. The second problem deals with the complexity of interpreting results from the answers of the "select all that apply" types of questions. The researcher is often questioning if students left the selection blank because they thought it was false and how would the researcher be able to determine if that was the case. This devalues these types of assessment questions. Another issue with item construction involves linking items on the test. For example, GCI item number 10 should not ask students about their response to GCI item number 2. Research in assessment development shows that asking students to complete additional tasks besides just answering the question, interferes with how the student responds to the question (Downing & Haladyna, 2006).

Since 2008, there has been very little published about developing a new GCI instrument. The most notable is an un-refereed newsletter article published by Libarkin and colleagues (2011), which describes the need to revise the first *Geoscience Concept Inventory* (GCI v.1.0), stating, "We are now retiring GCI v.1.0 and rebuilding the GCI as a more community-based, comprehensive, and effective instrument." These authors recognize the weaknesses in the GCI v.1.0, many of which were previously listed above. These authors also discuss the benefits of collaboratively revising the GCI v.1.0. Their article called for geologists, science educators, and instrument developers to participate as reviewers and authors of new questions. Since that time (2011), there has been no formal publication of the "new" GCI. Five years have passed and the geology education community is still using the original GCI. Such a situation suggests the community is ready for a new assessment instrument.

It is reasonable to question the planned revisions for the new GCI and the weaknesses of those proposed revisions. Libarkin (2011) suggested the "expansion to more complex, wider ranging questions" (p. 1) which "will allow replicable assessment in advanced courses and across geoscience programs" (p. 1). Help was requested from "experts knowledgeable about issues students have understanding complex ideas (p. 2)" to "write, review, and test new questions" (p. 2). While this is one approach to developing a survey instrument, the researchers still faced two main challenges.

First, the researcher was faced with the challenge of identifying the content to be included on the new instrument. It does not appear that any next generation GCI is intended to be aligned purposefully to any national standards documents—including the AAAS *Benchmarks* (1993), NSF *Earth Science Literacy Principles* (2008), NRC *National Science Education Standards* (1996), Achieve Inc.'s *Next Generation Science Standards* (2013b)—meaning even after proposed revisions the GCI will not be a true criterion-referenced test (CRT). The content included will be content that various individuals deem important. In education literature we've known from as early as the 1970s, that instruction and assessment design are directly linked to clearly stated learning objectives (Tamir & Jungwirth, 1972). The GCI v.1.0 wasn't aligned to national science standards reform efforts and as a result lacks the wisdom of the broader community.

Libarkin (2011) recognized the weaknesses in the GCI v.10 and planned to revise it; however, as previously stated, it has been five years and the geology education community is still lacking a comprehensive assessment instrument designed to measure students' general geology content knowledge. In the current project described here, our development effort leverages the strengths and mitigates the weaknesses of the GCI in hopes that science educators will find a new instrument to be fruitful and easy-to-adopt across the nation.

Approach to EGGS Survey Development

To avoid difficulties of earlier geoscience conceptual assessment projects, there were multiple stages used to address criterion and content validity of the proposed *Exam of GeoloGy Standards*, EGGS. The systematic development and validity process of the Test Of Astronomy STandards, *TOAST* (Slater, 2014) was closely followed during the development of the EGGS. The first stage included the development of a standard aligned consensus document (Guffey, Slater, & Slater, 2017, *in review*). This ensures that EGGS is a criterion-referenced test (CRT). The standards were aligned from the following four validated national science education reform standards documents: the American Association for the Advancement of Science (AAAS) *Benchmarks for Scientific Literacy* (1993), the National Research Council (NRC) *National Science Education Standards* (1996), the National Science Foundation (NSF) *Earth Science Literacy Principles* (2010), and the National Research Council (NRC), the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS), and Achieve Inc's, *Next Generation Science Standards* (2013b). The resulting consensus was distributed to 137 geology experts (with a 29% return rate) across the country requesting feedback and comments regarding the geology standards and was revised based on the received feedback. The alignment of standards on the consensus document was used as the base criteria on the EGGS. This systemic process resulted in the bare minimum of what students should know when leaving an introductory geology course.

There were two purposeful efforts to address construct validity. First, as the goals consensus was finalized, but before test item construction began, a literature review of geology cognition was completed (Guffey & Slater, 2017, *in review*). Being aware of misconceptions and how people think about geology concepts helps facilitate the test item construction process. Questions were pulled from previous peer-reviewed, empirical literature in the geosciences. For example, Marques and Thompson (1997a) performed a study to identify middle and high school students' misconceptions of plate tectonics. During the study students were asked particular questions to probe their thought process of plate tectonics. These are the types of questions that were used from peer-reviewed, empirical literature for the EGGS. The second step that addressed construct validity included the actual item construction, which was modeled after Slater's *TOAST* (2014). All questions were written at a 7th grade reading level to ensure that EGGS would not be primarily assessing reading ability, and predominantly assessing geology conceptual understanding.

After identifying the questions used on the EGGS, the same process that was used to address criterion and content validity were used to start the process of assessing face validity. Geology experts reviewed the test items, provided feedback, and revisions were made. The last step to address face validity involved the distribution of the EGGS to individuals outside of geology and geology education. The outsider's perspective helps to determine the extent to which EGGS is well designed and how it appears "at face value."

Under-girding all of this is the systematic identification of the most commonly agreed upon teaching goals for introductory geology teachers (Guffey, Slater, Slater, 2017, *in review*) and simultaneously a thorough investigation of the scholarly literature reporting students' misconceptions related to these consensus goals is presented in detail elsewhere (Guffey & Slater, 2017, *in review*). Taken together, this motivates and enables our research and development effort to establish the validity and reliability of a new, easy-to-administer conceptual diagnostic for geology professors presented here.

METHODS

In an effort to establish the validity and reliability of an instrument for measuring students' understanding of geology concepts, this effort employs a well-established sequential explanatory design (Creswell & Clark, 2011). In this approach, the underlying assumption is that the researcher knows the important variables and has access to quantitative instruments for measuring the constructs of primary interest in addition to having the ability to return to participants for a second round of qualitative data collection. Ultimately, the researcher develops new questions based on qualitative results that cannot be answered with quantitative data, which leads to qualitative data collection and analysis. This study began with the quantitative strand, collecting closed-end data with a survey, the EGGS *Exam of GeoloGy Standards*, which is found in Appendix B. The researcher analyzed the quantitative results which were used to complete the following: 1) Refine the qualitative and mixed methods questions; 2) Determine which participants will be selected for the qualitative sample and; 3) Design qualitative data collection protocols. The researcher then collected open-ended data with protocols in the form of interviews. Qualitative data were analyzed using procedures of theme development to answer the qualitative and mixed methods research questions. Quantitative and qualitative results were interpreted separately. Mixing will occur when discussing to what extent and in what ways the qualitative results help explain the quantitative results.

Participants

The target population was non-science majoring undergraduate students, enrolled in introductory science survey courses in U.S. universities and colleges. The students were varied in terms of their GPA, major, number of science courses taken, and the degree they are pursuing. Criteria for selecting the participants included: 1) being enrolled in an introductory science survey course; 2) time period of Spring 2017; 3) must be in the beginning of the semester; and 4) undergraduate student status. A total of 194 students completed the EGGS assessment with six of those students being selected for follow-up interviews. In the first phase, assigning unique numeric passwords to each participant allowed them to access the web-based survey, which protected the anonymity of the participants. In the second phase, the participants selected for interviews were assigned fictitious names, thus keeping the responses confidential. In addition, all the names and gender related pronouns were removed from the quotations used for illustrations.

Quantitative Phase

Data Collection

For the first, quantitative phase, the EGGS *Exam of GeoloGy Standards* was administered online and accessed through *SurveyMonkey*. Active email addresses of potential participants were obtained through introductory science course professors and identified through other sources. The participants were recruited via e-mail a week before the beginning of the study. The data collection took place the first week of the Spring 2017 academic semester. The final version of the multiple-choice instrument used for this portion of the study is included in the appendix.

Data Analysis

Varma (2008) recommends conducting a detailed item-by-item analysis of multiple-choice items created for surveying conceptual understanding. Student responses were analyzed using the statistical analysis software program, *IBM SPSS Statistics*, to calculate Cronbach's alpha values, inspect item difficulty levels, and item discrimination indices. To ensure internal consistency of the EGGS, reliability was established by calculating Cronbach's alpha. To further establish the sufficient sensitivity of the instrument, two aspects of classic test theory were analyzed for the EGGS: item difficulty and item discrimination. Based on extensive and successful work in the realm of conceptual knowledge survey development cited earlier, this approach was judged to be a more fruitful approach than more often heralded, but rarely used correctly, contemporary IRT item response theory (Wallace & Bailey, 2010).

The researcher randomly selected six students from those who volunteered to complete the EGGS and participate in think-aloud interviews. Using a straightforward clinical interviewing technique, interviewees were asked to elaborate (discuss their thinking out loud) on each question. The researcher only recorded field notes, which were compared to the geology misconceptions literature to see if students hold the same misconceptions found in the literature, or if new notions became apparent.

Qualitative data were analyzed by performing a comparative analysis between the field notes collected in the interview and the geology misconceptions found in the literature. Upon completion of the analysis, the researcher developed an organized list of themes, which included the geology misconceptions. The list of organized themes were compared to the quantitative results. At this point, the researcher synthesized geology misconceptions that weren't identified upon completion of the quantitative analysis of the EGGS.

RESULTS

After several earlier iterations and pilot-testing of EGGS items, the final published 1.0 version of EGGS was administered to students enrolled in their first week of a college-level introductory science survey course designed for non-majoring undergraduates. Overall, 172 participants scored an average of 42% correct with a standard deviation of .014. The Cronbach Alpha was 0.69 and the average item discrimination was 0.34. Taken together with supporting interview data, we argue that this published version 1.0 of EGGS is a valid and reliable instrument to elicit students' misconceptions.

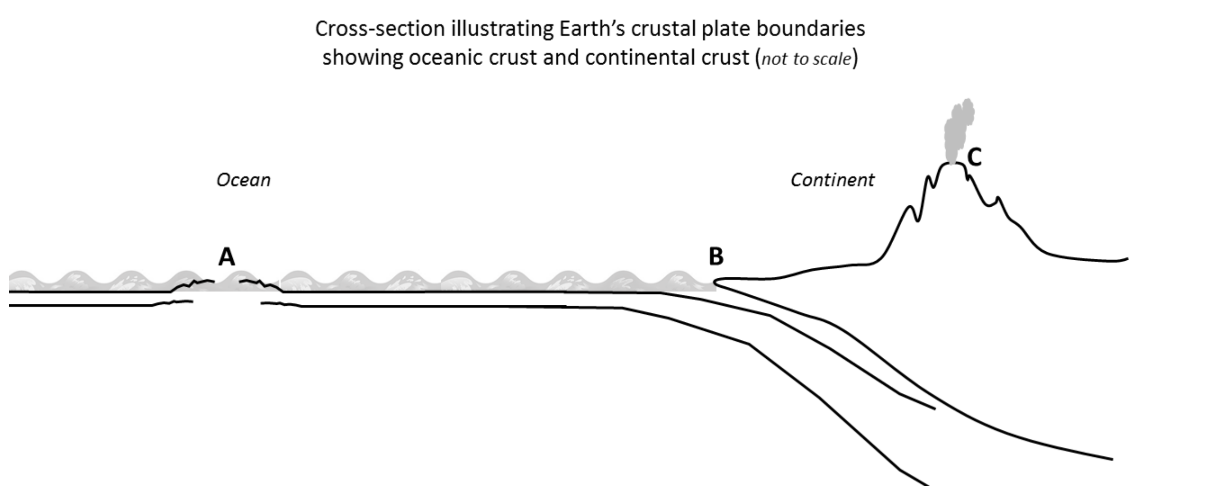
EGGS Concept 1: ***Earth's crust is broken into plates, which slowly move in relationship to each other, driven by convection currents in the mantle.***

Figure 1. Item Analysis for EGGS Question 1

Q1. About how far do Earth's continents—and the plates they ride on—move in a single year?		
Response Labels	**Item difficulty**	**Item discrimination**
a. A few inches	**0.81**	0.45
b. A few hundred feet	0.11	
c. A few miles	0.05	
d. Continents and plates do not really move	0.03	

Figure 2. Item Analysis for EGGS Question 5

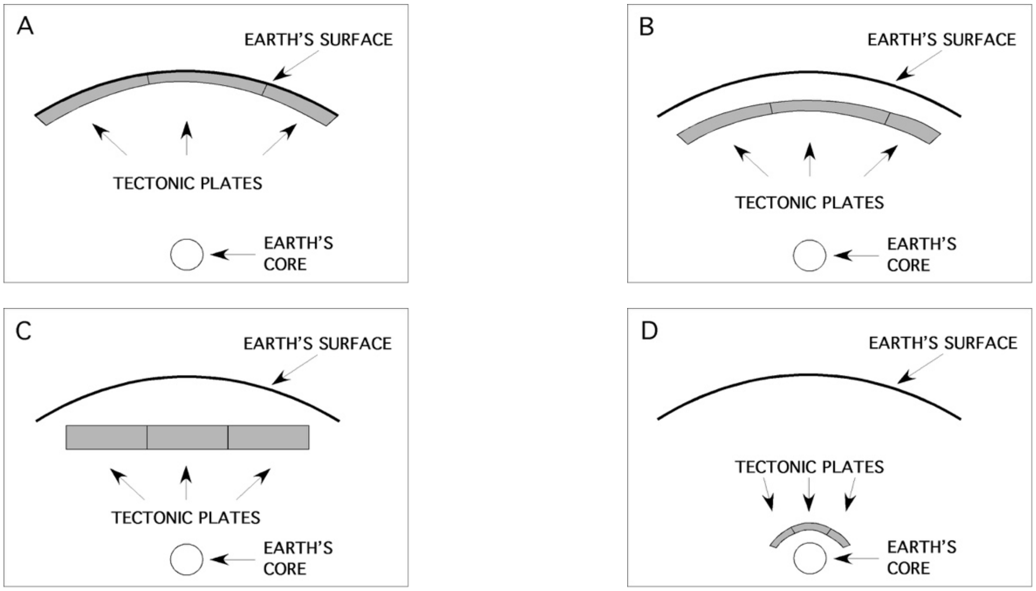
Q5. Which letter on the diagram above illustrates a location where Earth's plates are moving APART?



Response Labels	Item difficulty	Item discrimination
a. A	**0.51**	0.52
b. B	0.15	
c. C	0.01	
d. Both locations A & B are moving apart	0.33	

Figure 3. Item Analysis for EGGS Question 6

Q6. Scientists often talk about Earth's tectonic plates and their role in mountain formation, volcanoes, and earthquakes. Which of the following figures most closely represents the location of Earth's tectonic plates?



Response Labels	Item difficulty	Item discrimination
a.	**0.51**	0.63
b.	0.36	
c.	0.11	
d.	0.02	

Three questions were designed or adapted to measure students' understanding of plate tectonics as the central theory of geology. Question 1 was adapted from AAAS Project 2061 Science Assessment (AAAS, n.d.) assessment item PT019001 in order to measure student's understanding of plate movement rates. AAAS reports 62% of students grades 6-8 and 68% of students grades 9-12 correctly identify the rate of plate movement as several inches per year. College students in our study answer this question at a slightly higher rate of 81% correct.

Question 5 is adapted from Clark and Libarkin (2011a) and Clark (2011b) and colleagues who report students often confuse spreading ridges with hot spots and are unable to identify directional motion of plates at boundaries without arrows being provided. Although Clark (2011b) does not report frequency of this misconception, our results show that only 51% are able to identify a divergent boundary on a diagram without arrows. It is worth noting that our question used the words "moving apart" as opposed to "divergent boundary" in order to use more natural student language in contrast to scientific vocabulary. Question 6 is adapted from the *Geoscience Concept Inventory*. Libarkin and Anderson (2005a) report 56% of 2,483 students have misconceptions about the location of tectonic plates. These results are also similar to our results.

In the follow-up interviews, participants hold prominent misconceptions in terms of Earth's plates and how they move. In regard to question 5, 51% answered the question correctly with the majority of other respondents selecting B (15%) or D (33%). One participant stated, "I know volcanoes form when plates move apart however; this diagram doesn't display plates moving apart." The diagram displays a cross-section illustrating Earth's crustal plate boundaries with oceanic and continental crust. Point A on the diagram represents a divergent boundary, which is where Earth's plates are moving apart. The respondent viewed this as the "ocean being closed off so there is no pressure to build a volcano," which is a commonly held misconception that volcanoes form because of pressure. Another respondent stated, "When I hear the word 'plates' I think of the ground itself. When plates are moving apart, the mass of ground moves into deeper locations, but not in shallow places like the ocean. So the plates are moving apart at B." This response supports the misconception of not being able to accurately identify a divergent or convergent boundary in addition to what happens to plates at the various boundaries.

Question 6 focuses on the location of Earth's plates. Fifty one percent of respondents were able to correctly identify the location of Earth's plates in relation to Earth's surface. However, 36% believe that Earth's surface and its tectonic plates are separate from each other (B). In follow-up interviews, one respondent stated, "The tectonic plates [separate from Earth's surface] are the one's that move and shift to cause earthquakes. They have to be close to Earth's surface otherwise we wouldn't feel the earthquakes." This confirms that students are often confused on the location of Earth's plates.

EGGS Concept 2: ***Atoms of different elements combine to make minerals, which combine to make rocks. Rocks and minerals are classified by their chemical and physical properties.***

Figure 4. Item Analysis for EGGS Question 2

Q2. Which of the following construction and building materials is ***NOT*** actually a rock?		
Response Labels	**Item difficulty**	**Item discrimination**
a. Slate	0.17	
b. Brick	**0.70**	0.37
c. Marble	0.09	
d. Granite	0.04	

Figure 5. Item Analysis for EGGS Question 3

Q3. How deep is an oil well drilled?		
Response Labels	**Item difficulty**	**Item discrimination**
a. As deep as a football field is long	0.31	
b. About a mile	**0.50**	0.42
c. Halfway to Earth's center	0.18	
d. To Earth's center	0.01	

Figure 6. Item Analysis for EGGS Question 4

Q4. We can best determine the environment in which lava or magma solidifies and becomes a rock by using the rock's		
Response Labels	**Item difficulty**	**Item discrimination**
a. Density	0.23	
b. Mineral grain sizes	**0.06**	0.12
c. Texture	0.10	
d. Temperature	0.18	
e. Chemical composition	0.43	

Question 2 was adapted from work by Dove (1996) who reports pre-service teachers rarely identify common building and construction materials as rocks in interviews. Only seventy percent of students in our study correctly identified brick as a non-rock. Question 3 was adapted from Rule (2005) who reported that students in his study lack sufficient conceptual framework to accurately predict location of fossil fuels. This misconception was true for 50% of students in our study.

Question 4 was created in response to research by Ault (1982) who found that primary students associate a crumbly texture or darker color as being indicative of the oldest rocks and by Ford (2006) who reports that most of the 55 middle school students studied believe rocks are characterized on the basis of their shape. Nearly one quarter focus on superficial physical characteristics when categorizing rocks, like shape. This is similar to Happs' (1982) report that students simply characterize rocks based on their weight. Our results are consistent with this research and show that most students mistakenly believe rocks are categorized predominantly by chemical composition or density.

In follow-up interviews, participants suggested that oil can be found deeper than a mile, but "it wouldn't be safe because of built up pressure." Students are confused on the location of fossil fuels and the reasons why fossil fuels exist in particular areas. In regards to categorizing rocks, only 6% of students understand that mineral grain sizes are used. In follow-up interviews one participant stated, "You are able to identify a rock if you know the chemical composition and temperature. For example, I know lava can create crystals and diamonds so from that you are able to figure out the temperature and determine where the rock came from." Another participant also believes temperature is used to identify rocks by stating, "Magma is hotter than lava so temperature makes sense." Rock classification is a concept that students consistently struggle with.

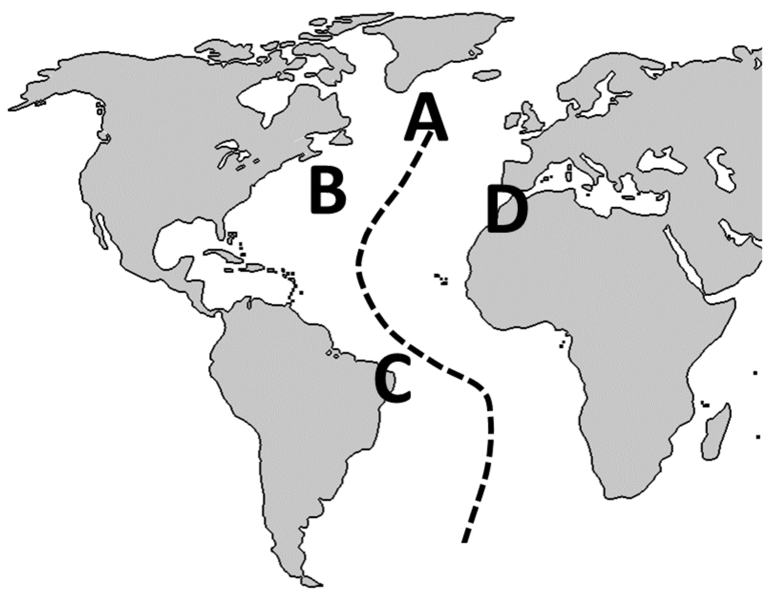
EGGS Concept 3: ***Earth materials take many different forms as they cycle through the geosphere. Rocks form from the cooling of magma, the accumulation and consolidation of sediments, and the alteration of older rocks by heat, pressure, and fluids. These three processes form igneous, sedimentary, and metamorphic.***

Figure 7. Item Analysis for EGGS Question 7

Q7. Primarily, why do sediment grains stick together to form?		
Response Labels	**Item difficulty**	**Item discrimination**
a. Pressure	**0.56**	0.48
b. Heat	0.17	
c. Erosion	0.10	
d. Chemical bonding	0.17	

Figure 8. Item Analysis for EGGS Question 8

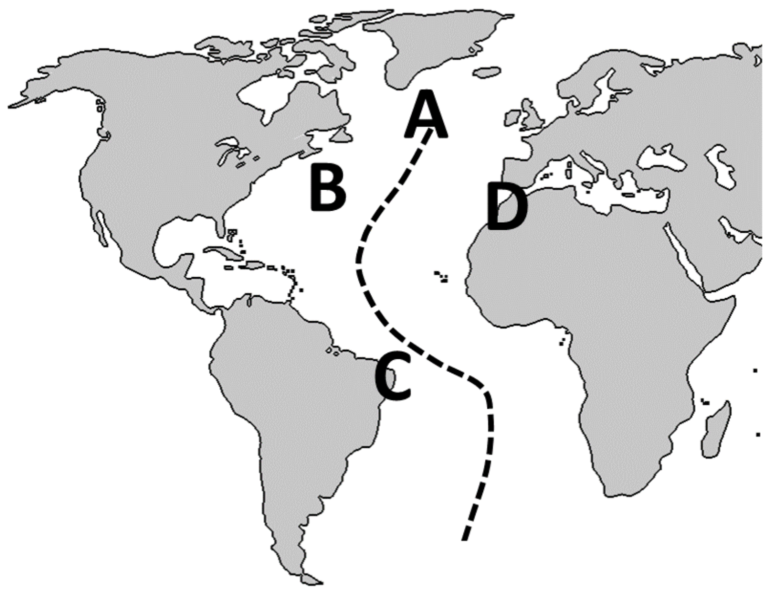
Q8. Imagine rock samples were gathered from Earth's crust in each of the marked locations. Rank the collected rock's ages in order from youngest to oldest.



Response Labels	Item difficulty	Item discrimination
a. YOUNGEST ← A < B < C < D → OLDEST	0.16	
b. YOUNGEST ← D < C < B < A → OLDEST	0.23	
c. YOUNGEST ← A < C < B < D → OLDEST	**0.35**	0.20
d. YOUNGEST ← B < D < C < A → OLDEST	0.10	
e. YOUNGEST ← A < B < D < C → OLDEST	0.16	

Figure 9. Item Analysis for EGGS Question 9

Q9. Compared to Earth's crust at location A, the crust at location B is



Response Labels	Item difficulty	Item discrimination
a. Old, cold, and thick	**0.29**	
b. Dark, dense, and hot	0.16	0.35
c. Dense, cold, and young	0.31	
d. Dense, thick, and cold	0.24	

Question 7 was adapted from research by Stofflett (1993) who reports students do not understand rock formation, and often attribute formation to weather conditions across all rock types. Our results show that only half of students identify pressure as the primary process creating sedimentary rocks. Questions 8 and 9 were created to measure students' understanding that rocks cycle through the geosphere. Kusnick (2002) found that students interchange common words and technical vocabulary carelessly. Two-thirds of students in our study exhibit misconceptions in this domain.

In follow-up interviews, participants elaborated on why they believe heat causes sedimentary rock formation. One participant stated, "Heat melts things. Rocks are formed in the center of the Earth, which is hot, so it molds rocks together." Other participants attributed chemical bonding stating, "Rocks form through different particles such as sand, lava, and dirt. They stick together through chemical bonding and form rocks."

Question 8 asked students to compare rocks ages based on their location in Earth's crust. Before answering the question, participants tried to make sense of the diagram stating, "I believe the dotted line represents the ocean's current, flow of water, or international lines [North or South]." Two participants believed the rocks found at location B are the youngest because North America was discovered last and rocks found at location D are older because Africa has been around longer. Other participants attributed evolution in determining the age of rocks stating, "In terms of evolution, everything started in Africa [life, rock formation, landforms] so the rocks there would be the oldest." Lastly, some participants credited Pangaea stating, "This drawing represents Pangaea so Africa and North America would split first so those rocks would be oldest." Question 9 asked students to compare Earth's crust at two different locations in terms of age, density, and temperature. A few participants attributed the climate of particular locations stating, "I selected cold because the crust at location B looks like Canada and I know it's cold up there" and "The environment in New England is cold so the crust is cold too." Others focused on density and age stating, "The older something is, the more dense it is. With older areas, more dirt piles on top over time to make it more dense." Lastly, some participants credited soil and density stating, "The soil in New England is not fertile so it's dense and thick." These results are unique in that these mental conceptions have not been repeated elsewhere.

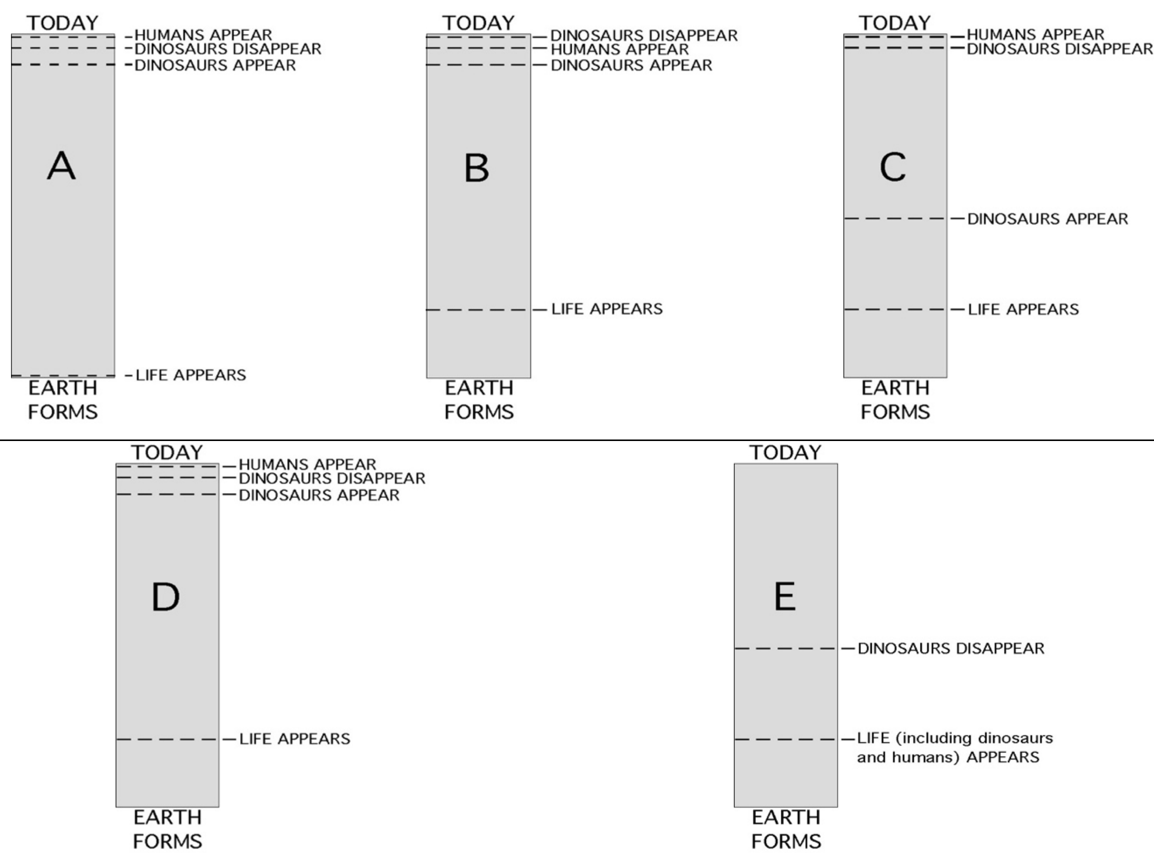
EGGS Concept 4: ***Earth's rocks allow us to reconstruct Earth's history, giving both relative and absolute dates.***

Figure 10. Item Analysis for EGGS Question 10

Q10. Which of the following best describes the relationships between humans (people) and dinosaurs?		
Response Labels	**Item difficulty**	**Item discrimination**
a. People and dinosaurs co-existed for about 5,000 years	0.06	
b. People and dinosaurs co-existed for about 500,000 years	0.02	
c. Dinosaurs died out about 5,000 years before people appeared on Earth	0.26	
d. Dinosaurs died out about 5,000,000 years before people appeared on Earth	0.43	
e. Dinosaurs died out about 50,000,000 years before people appeared on Earth	**0.23**	0.08

Figure 11. Item Analysis for EGGS Question 11

Q11. Which of the figures below do you think most closely represents changes in life on Earth?



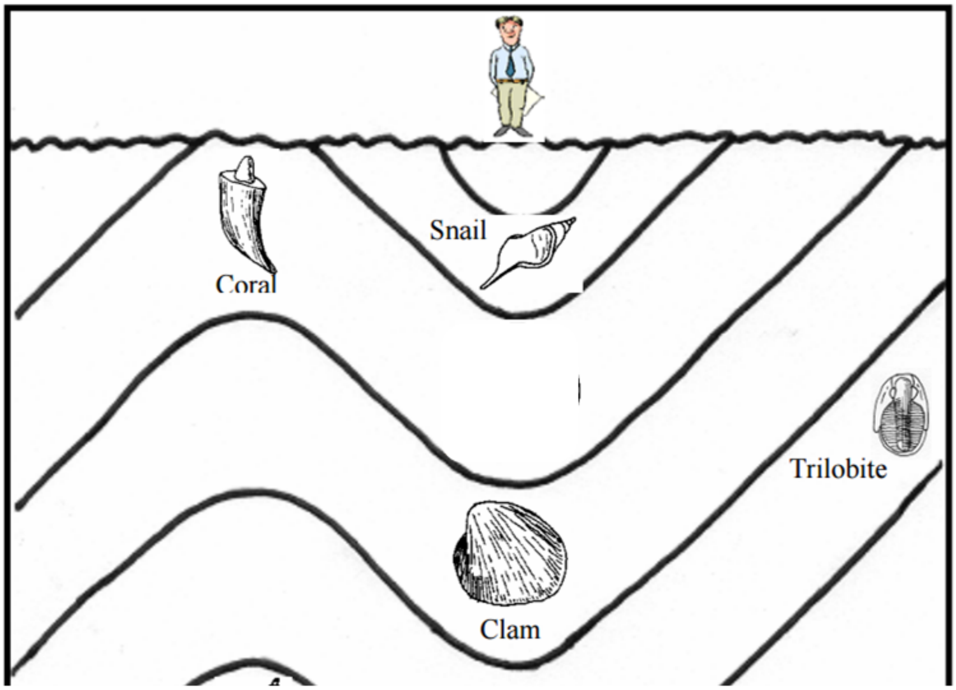
(Figure 11 continued on next page)

(Figure 11 continued)

Response Labels	Item difficulty	Item discrimination
a.	0.14	
b.	0.10	
c.	0.41	
d.	**0.26**	0.32
e.	0.09	

Figure 12. Item Analysis for EGGS Question 12

Q12. A geologist in the diagram is standing on marine sedimentary rock containing fossils. What is the order of fossils according to their age from oldest to youngest?



Response Labels	Item difficulty	Item discrimination
a. OLDEST ← trilobite, clam, coral, snail → YOUNGEST	**0.63**	0.47
b. OLDEST ← clam, trilobite, snail, coral → YOUNGEST	0.14	
c. OLDEST ← coral, clam, snail, trilobite → YOUNGEST	0.07	
d. OLDEST ← clam, trilobite, coral, snail → YOUNGEST	0.16	

Question 10 is adapted from the *Geoscience Concept Inventory* item number 36 (Libarkin & Anderson, 2005a), and is based on research from Schoon (1992), Schoon and Boone (1998), Libarkin, Kurdziel, and Anderson (2007), and Trend (2001) reporting that many students think humans and dinosaurs coexisted. Our results are consistent with the idea that students do not fully understand the large difference in time between the existence of humans and the existence of dinosaurs. Only one quarter of students in our study correctly identify that dinosaurs died out more than 50 million years before the existence of humans. Where are our results markedly differ is that the vast majority of students in our study did not say that humans and dinosaurs coexisted; instead, two-thirds of respondents answered that dinosaurs died out between 5,000 and 5 million years before humans appeared. These results are consistent with Trend (2000) who found students underestimate timescale lengths. We judge this near zero item discrimination to be acceptable because of the small number of students that answered this question correctly. One might wonder if students are thinking about birds as being a closely linked ancestor of dinosaurs, which is causing some confusion; however, none of our interviewees made this claim in describing their thinking.

Question 11 is adapted from the *Geoscience Concept Inventory* item 28 (Libarkin & Anderson, 2005a) and is based on research reported by in Libarkin, Kurdziel, and Anderson (2007). Petcovic and Ruhf (2008) report 75% of pre-service teachers incorrectly answer this question on a pre-test and 55% answer incorrectly on a post-test, suggesting that Earth's timescale is a tenacious misconception. Their data is wholly consistent with our results where 26% answer correctly suggesting that students' misconceptions are pervasive in this domain.

Question 12 is adapted from research by Dodick and Orion (2003) on their GeoTAT assessment, puzzle 1. Although Ault (1982) reports that young children can appropriately employ principles of superposition and original horizontality, results from the GeoTAT reveal students give depth as a priority in determining relative age when considering horizontal layers. Dodick and Orion (2003) report that about 80% of students can answer this item correctly. Our results show a larger percentage of students struggle with this idea as only 63% of students answer correctly.

In follow-up interviews, participants stated that humans and dinosaurs did not coexist; however, they are unsure of the time scale of when dinosaurs died and humans appeared. Participants in follow-up interviews believe that when Earth formed there was also some form of life stating, "Most likely plant life existed at the time of Earth's formation." In terms of the principles of superposition and horizontality, participants are aware that fossils found in deeper layers of Earth's crust are older. Taken together, students' misconceptions about the nature of deep time are widespread.

EGGS Concept 5: ***Fossils provide evidence about the types of organisms that lived long ago and the nature of the environments at that time.***

Figure 13. Item Analysis for EGGS Question 13

Q13. Most species of living things alive today		
Response Labels	**Item difficulty**	**Item discrimination**
a. Have existed since the time life began.	0.11	
b. Have existed since the time life began, but new ones have now appeared too.	0.37	
c. Did not exist when life began on Earth.	**0.52**	0.63

Figure 14. Item Analysis for EGGS Question 14

Q14. The scientific term "fossil" refers to		
Response Labels	**Item difficulty**	**Item discrimination**
a. Remains of once living things.	0.24	
b. Remains of living things AND traces, like preserved footprints.	**0.59**	0.57
c. Once living things that are now extinct and no longer live anywhere on Earth.	0.17	

Question 13 is adapted from AAAS Project 2061 Science Assessment project, item EN055001, intended to measure students' misunderstanding that all species began at the same time and still exist today (AAAS Project 2061, n.d.). AAAS reports 46% of students grade 6-8 and 52% of students grades 9-12 correctly respond that most species living today did not exist at the time life began. AAAS reports that 8% of students in their study exhibit this misconception. This result is similar to our study where only 11% of students exhibit this misconception. It does not appear that this mistaken notion is as widespread as one might predict.

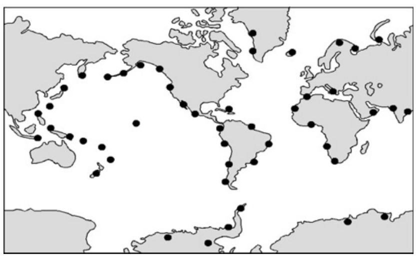
Question 14 is heavily modified from AAAS Project 2061 Science Assessment project, item EN013002, to measure students' understanding of how scientists conceive of fossils. AAAS reports 48% of grade 6-8 and 55% of students grades 9-12 correctly identify that fossils can be made through replacement or impressions. In our study 59% of students answer correctly, whereas 25% believe fossils are remains of once living things. These results are consistent with Petcovik and Ruhf (2008), who found students only conceive of fossils as remains of living things. Oversby (1996) describes pre-service teachers' misconceptions that only living things, like plants and animals, that have undergone fossilization are considered fossils. In other words, many students would not consider an unfossilized shark tooth or a mold of an animal track a fossil. These results do not speak to research by Dodick and Orion (2003) who report students think older fossils are always less complex than more recent fossils.

In follow-up interviews participants leaned on the theory of evolution when thinking about species that exist today stating, "With evolution we know that new life forms have appeared in addition to what's existed since life began; most living things have evolved over time." When defining the word "fossil" several participants selected the correct answer because they remembered learning vocabulary terms [trace fossils] in elementary and middle school.

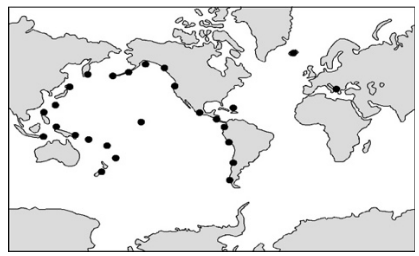
EGGS Concept 6: ***Earthquakes, mountain building, volcanic activity, and ocean floor features occur at plate boundaries as the result of plate movement.***

Figure 15. Item Analysis for EGGS Question 15

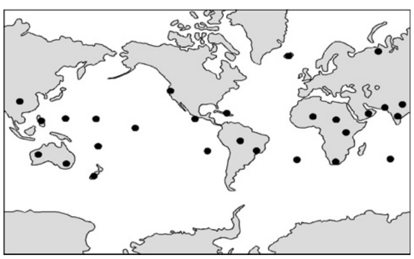
Q15. The maps below show the position of the Earth's continents and oceans. The ● symbols on the maps mark the locations where **VOLCANIC ERUPTIONS** occur on land. Which map do you think most closely represents the places where these volcanoes are typically observed?



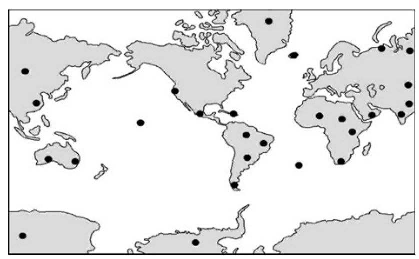
A. Mostly along the margins of the Pacific and Atlantic Oceans



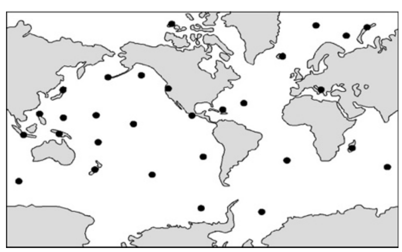
B. Mostly along the margins of the Pacific Ocean



C. Mostly in warm climates



D. Mostly on continents



E. Mostly on islands

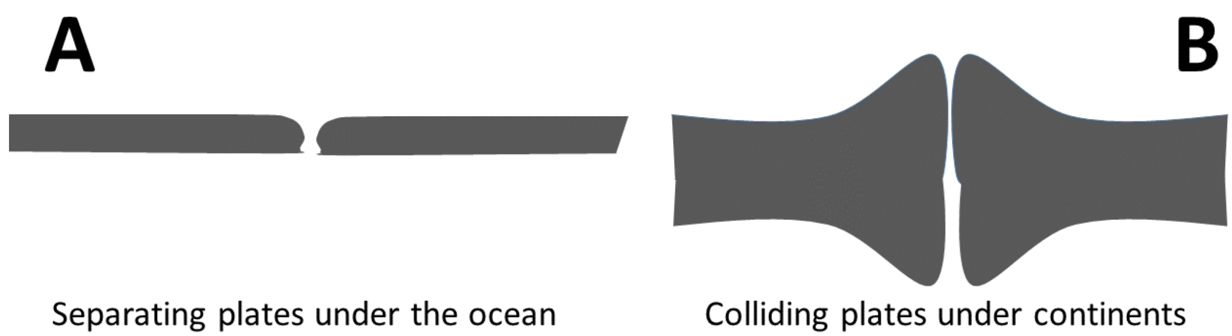
Response Labels	Item difficulty	Item discrimination
a. Mostly along the margins of the Pacific and Atlantic Oceans	0.26	
b. Mostly along the margins of the Pacific Ocean	**0.38**	0.38
c. Mostly in warm climates	0.12	
d. Mostly on continents	0.09	
e. Mostly on islands	0.15	

Figure 16. Item Analysis for EGGS Question 16

Q16. Why are volcanoes and earthquakes often studied together?		
Response Labels	**Item difficulty**	**Item discrimination**
a. Earthquakes force lava upwards	0.03	
b. Earthquakes cause volcanoes	0.07	
c. Both occur at plate boundaries	**0.49**	0.48
d. Both are caused by pressure pushing upward from underneath	0.41	

Figure 17. Item Analysis for EGGS Question 17

Q17. Which of the plate boundaries shown below as cross-sections are most likely to produce volcanoes?



Response Labels	Item difficulty	Item discrimination
a. Separating plates under the ocean	**0.30**	0.23
b. Colliding plates under continents	0.70	

Question 15 is adapted from the *Geoscience Concept Inventory*, item number 13 (Libarkin & Anderson, 2006) and measures students' understanding of volcano locations at plate boundaries. Petcovik and Ruhf (2008) report 55% of pre-service teachers answer correctly on a pre-test, increasing to 54% answering correctly on a post-test. In our study 62% of students incorrectly identify the locations of volcanoes and plate boundaries. This is wholly consistent with the misconception that continental margins are plate boundaries. Only 38% of our respondents correctly answered choice B. This item appears to be working as anticipated and consistent with research reported by Parham (2010) and colleagues. They created the 10-item student-supplied-response Volcanic Concept Survey and administered it to 672 students across five universities. The goal of the survey was to identify conceptual domains where introductory geology students had deficits in their understanding of volcanoes. Their study uncovered four dominant misconceptions about the formation of volcanoes: 1) Volcanoes only form near bodies of water (17%); 2) Volcanoes are common only in areas near the equator or other warm areas (15.2%); 3) Volcanoes appear in areas of rocky terrain (6%); and 4) There is no pattern to geographic locations where volcanoes form (50.4%).

Question 16 is adapted from research by Barrow and Haskins (1996) who administered a questionnaire to 186 college students prior to college level instruction—it was assumed that all students had experienced at least a modicum of Earth science instruction during their K-12 learning experiences. When asked why earthquakes and volcanoes are often studied together, 17% of students described that earthquakes cause volcanoes, mostly because earthquakes force lava upward. Only 6% suggested that volcanoes form when plates collide or occur at plate boundaries. In our study about half answered correctly that volcanoes and earthquakes are often studied together because of action at plate boundaries. We also found that 41% of students answered that both are caused by pressure pushing upward from underneath, suggesting that this item is detecting a widespread misconception.

Question 17 was created from a surprising lack of published research surrounding sea floor spreading. Experienced geology teachers know that students naturally assume that divergent plate boundaries result in deep chasms at the bottom of the ocean, rather than submarine mountain ranges caused by upwelling magma. Interview research of 26 middle school students by Ford and Taylor (2006) found that some students think there are large gaps or spaces between Earth's plates. Seventy percent of our students believe that volcanoes are more likely to result from colliding continental plates than diverging oceanic plates. These results suggest that this is a rich area for future exploratory research.

In follow-up interviews several participants believe volcanoes form when two pieces of land come together. One participant selected A (mostly along the margins of the Pacific and Atlantic oceans) stating, "volcanoes form when oceanic and continental plates come together." Another participant selected D (mostly on continents) because "there are some volcanoes in water but mostly are underground and on land [not in water]." Another participant stated volcanoes form when "two pieces of land come together at an angle so they probably form most often on islands." This participant went on to address continental drift stating, "I know with continental drift the plates didn't line up. One piece of land overtook another piece of land and the core came up through the middle of the Earth. But I know that volcanoes make new land." Another participant specifically stated why volcanoes do not form in warm climates stating, "It already hot in warm climates so there wouldn't be volcanoes."

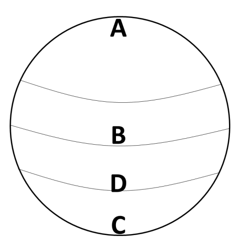
When asking students why volcanoes and earthquakes are studied together in follow-up interviews, most participants attributed the linking concept as pressure. One participant stated, "Both are caused by pressure pushing up from underneath. The center of the Earth has a lot of energy and movement, which causes pressure. Volcanoes blow up [erupt] through a release valve from too much pressure. Earthquakes don't have a release valve so the plates move [instead of erupting]. Earthquakes and volcanoes are the same concept but they occur in different locations." Other participants believe earthquakes force lava upwards stating, "Earthquakes cause disruptions in volcanoes and if it's intense enough then it will cause the volcano to erupt."

When asking students which plate boundaries are most likely to produce volcanoes in follow-up interviews several participants selected colliding plates under continents. One participant attributed pressure stating, "With the plates separating there wouldn't be any force/pressure going up." Another participant stated, "When two pieces of land come together, they push up to form volcanoes." Another participant attributed mountains stating, "This diagram looks like it's forming a mountain and I know that mountains are sometimes volcanoes." These domains represent an important area for targeted curriculum development to enhance students' understanding.

EGGS Concept 7: ***The Earth has a layered structure with a dense metallic core, hot convecting mantle, and a brittle crust.***

Figure 18. Item Analysis for EGGS Question 18

Q18. The most dense part of Earth is near which point?



Response Labels	Item difficulty	Item discrimination
a. North pole	0.07	
b. Earth's center	**0.67**	0.35
c. South pole	0.07	
d. Above South Pole, but below center of Earth	0.19	

Figure 19. Item Analysis for EGGS Question 19

Q19. The very center of Earth is mostly made of		
Response Labels	**Item difficulty**	**Item discrimination**
a. Gases.	0.06	
b. Liquids.	0.22	
c. Solids.	**0.40**	0.48
d. A combination of gases, liquids, and solids.	0.32	

Question 18 was adapted from research by Marques and Thompson (1997) to measure students' understanding of the changing density of Earth's interior. They found that 42% of students believe the densest part of the Earth is not the center, but a position between the center and South Pole. This is consistent with our results showing that nearly 20% of students believe the densest part of Earth is south of the equator. Only 67% of our respondents pinpoint Earth's center as the densest point. These results add weight to tangential research by Sneider and Ohadi (1998) that students' misconceptions about gravity, and the nature of which direction is up in space, are well poised to interfere with geology instruction.

Question 19 was included because the literature suggests that a significant number of students are unable to accurately identify the physical phase of either the core or Earth's mantle. King (2000, 2008) reports many students conceptualize the Earth as a sphere of molten, liquid magma contained by Earth's thick, solid crust. Clark (2011) and colleagues also report that college students in their study conceive of the mantle as being predominantly liquid. McAllister (2014) found that 22% of the 92 undergraduates she interviewed have no coherent conceptual model of Earth's interior that reflect current scientific understanding. In fact only 9% of the 92 undergraduates could describe and sketch comprehensive conceptual models that were accurate. These results are similar for international students studied by Capps, McAllister, and Boone (2013). In our study we found that only 40% of students believe the very center of the Earth is solid and 32% mistakenly believe the very center of the Earth is a combination of gases, liquids, and solids. These results confirm that robust misconceptions exist regarding the nature of Earth's interior.

In follow-up interviews several participants describe the densest part of the Earth as being at the South Pole. One participant attributed weight and gravity stating, "It's at the bottom because the weight and gravity are pushing down which makes it more dense." Another participant compared the North and South Poles stating, "At the North Pole it's just an ocean so it's not as dense. The South Pole has Antarctica with lots of ice and land mass which makes it very dense." In follow-up interviews some participants believe the center of the Earth is mostly made of a combination of gases, liquids, and solids stating, "I know the gases build pressure. There is heat which needs something to burn which creates molten lava and solids." These results lend weight to the power of these items to successfully identify well-known misconceptions.

EGGS Concept 8: ***Earth's interior is heated primarily by radioactive decay and gravitational energy.***

Figure 20. Item Analysis for EGGS Question 20

Q20. Most scientists think that the inner most parts of Earth are incredibly hot. This high temperature mostly comes from energy		
Response Labels	**Item difficulty**	**Item discrimination**
a. Emitted from radioactive decay	**0.26**	0.00
b. Leftover from the not-yet-cooled Earth from its formation	0.38	
c. From the Sun	0.13	
d. Due to Earth's gravity	0.23	

Figure 21. Item Analysis for EGGS Question 21

Q21. If a 5 kilogram radioactive rock has a half-life of 50,000 years, this means that in 50,000 years, the rock will be		
Response Labels	**Item difficulty**	**Item discrimination**
a. 1 ¼ kilograms	0.04	
b. 2 ½ kilograms	0.49	
c. 5 kilograms	**0.25**	0.00
d. 10 kilograms	0.22	

Question 20 is adapted from the *Geoscience Concept Inventory*, item 27 (Libarkin & Anderson, 2006) who report students think Earth's hot interior is due to insufficient cooling rather than energy from radioactive decay. Petcovik and Ruhf (2008) report 25% of pre-service teachers are able to answer this item correctly on a pre-test and 41% answer correctly on a post-test. Our results were nearly identical, suggesting this item is well suited to identify this misconception, although it does not readily reveal what the underlying physical mechanism students are employing in their thinking. It should be noted that we find this near zero item discrimination to be acceptable because of the small number of students that answered this question correctly.

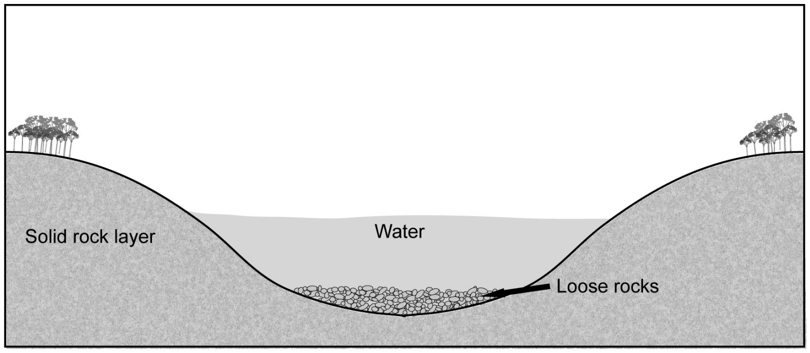
Question 21 is adapted from research by Prather (2005) who reports students have deeply entrenched misconceptions about half-life and radioactive decay. His interviews with college students revealed that students often equate radioactive decay with the disintegration of matter. In our study, 49% of students have misconceptions related to half-life, which is consistent with Prather's (2005) results. It should be noted that we find this near zero item discrimination to be acceptable because of the small number of number students that answered this question correctly.

In follow-up interviews several participants attribute heat leftover from the not-yet-cooled Earth from its formation to the heat in the center of the Earth. One participant admitted, "I'm not sure what radioactive decay is but I know when Earth formed it was hit by something else and knocked into orbit. It was really hot at first then cooled a little to allow plant life to form and then we had the great freeze. So I'm pretty sure Earth is still cooling." Another participant attributed gravity to the hot inner parts of the Earth stating, "gravity causes heat." In follow-up interviews some participants were unable to calculate the half-life of a radioactive rock. Some participants believed the rock wouldn't decrease in weight because, "The rock is already formed so it can't change over time. It could combine with other particles so it could weigh more but not less."

EGGS Concept 9: ***Rocks are chemically and physically weathered into smaller pieces, which are transported (eroded) by gravity, water, ice, and wind.***

Figure 22. Item Analysis for EGGS Question 22

Q22. In the cross-section of a river valley shown below, there are loose rocks on top of a solid rock layer. Can water make the valley deeper?



Response Labels	Item difficulty	Item discrimination
a. No, valleys do not get deeper.	0.02	
b. No, valleys can get deeper, but water cannot make them deeper.	0.16	
c. Yes, water can make the valley deeper by breaking off pieces of rock from the solid rock layer of the valley and by carrying loose rocks away from the valley.	**0.64**	0.37
d. Yes, water can make the valley deeper by carrying loose rocks away from the valley, but water cannot break off pieces of rock from the solid rock layer of the valley.	0.18	

Figure 23. Item Analysis for EGGS Question 23

Q23. Can water dissolve rock material and move the dissolved material to a new location, and deposit the dissolved rock material as solid rock?

Response Labels	Item difficulty	Item discrimination
a. Yes, water can dissolve rock, move dissolved solid rock material to a new location, and deposit dissolved rock material as solid rock.	**0.47**	0.33
b. No, although water can dissolve rocks, water cannot move dissolved rock material to a new location.	0.08	
c. No, although water can dissolve rock and can move dissolved rock material to a new location, dissolved material cannot become solid rock.	0.30	
d. No, water cannot dissolve rock.	0.15	

To measure student's understanding of weathering and erosion we adapted two existing items from the AAAS Project 2061 Science Assessment effort, WE015003 and WE032003. The first item was designed to test for the common misconception that landforms look similar today as they did many millions of years ago. For example, a river on earth today hasn't changed over time (Dove, 1998; Trend, 1998) and water cannot make a valley deeper or break rock (AAAS Project 2061, n.d.). AAAS reports that 60% of students grades 6-8 and 58% of 9-12 correctly answer C, with remaining 40% evenly distributed across other answers. The second item was designed to test the misconception that water cannot deposit dissolved rock as solid rock and cannot dissolve rocks (AAAS Project 2061, n.d.). AAAS reports that only 35% of students grades 6-8 and 39% of 9-12 correctly answer A, with 34% answering C. These results are similar to our results.

In combination, these two items appear to be working as designed. However, these items are not reflective of research by Dove (1997) reporting geography students being unable to distinguish between weathering and erosion or research by Blake (2005) reporting students often use unscientific descriptions or Martinez, Bannan, and Kitsantas (2012) reporting students appealing to unnatural explanations of changes to Earth's surface. Erosion and weathering appear to be a relatively unexplored conceptual domain that could be rich and fruitful for future research studies.

In follow-up interviews several participants believe that water can make the valley deeper but is unable to deposit larger rocks in other places. One participant stated, "Loose rocks makes me think of sediments but I don't think solid rocks can get carried away because they are too big and heavy. Water can erode rock over time but it is unable to carry away rocks." Other participants believe valleys are able to get deeper but water cannot make them deeper. One participant stated, "Water can cause erosion but it can't break rock. Breaking off rock would make the valley more shallow and it will eventually be completely gone [the sides of the valley will no longer be there]." This confirms that students still struggle with differentiating between weathering, erosion, and deposition.

Regarding the second item in follow-up interviews most participants believe water is able to dissolve rock and move it to a new location. However, some participants believe the dissolved material cannot become solid rock. Other participants believe that water cannot dissolve rock stating, "Water can't dissolve rock but it can move it."

EGGS Concept 10: ***Soil is formed by weathered rocks and decayed organic materials.***

Figure 24. Item Analysis for EGGS Question 24

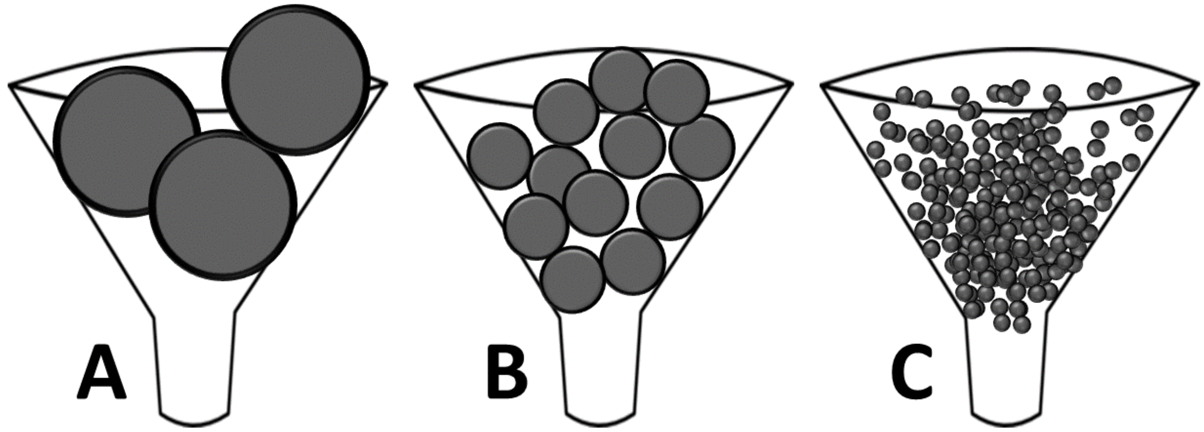
Q24. About how old is most of the soil near the location where you live?		
Response Labels	**Item difficulty**	**Item discrimination**
a. Tens to 100s of years old	**0.25**	0.02
b. Thousands of years old	0.26	
c. Millions of years old	0.27	
d. As old as Earth—it formed at about the same time	0.22	

Figure 25. Item Analysis for EGGS Question 25

Q25. About how deep is the soil where you live?		
Response Labels	**Item difficulty**	**Item discrimination**
a. A few inches, or a maybe a few feet, deep	**0.26**	0.22
b. As deep as a football field is long or more	0.33	
c. Several miles deep	0.32	
d. To nearly the center of Earth	0.09	

Figure 26. Item Analysis for EGGS Question 26

Q26. The figure below shows three funnels holding 10 kilograms of different sized rocks. In which case will water poured into the top pass through it MOST QUICKLY?



Response Labels	Item difficulty	Item discrimination
a.	**0.58**	0.48
b.	0.08	
c.	0.34	

These three items were developed based on limited research extant in scholarly literature base related to soils. Happs (1984) reports that 53% students he studied believe soil was formed as the point of Earth's formation, and 33% thought the average depth of soil is about one meter deep, and 23% believes soil does not evolve. Similarly, Hayhoe's (2013) review of soil science education curriculum materials resulted in his conclusion that students lack a consistent conceptual framework related to soil science. No empirical research seems to exist regarding the concept of porosity, even though experienced teachers tacitly know students struggle with this idea.

When asking students to elaborate in follow-up interviews regarding their answer choices for the age of soil, it is apparent that the majority of participants were guessing. This is consistent with the quantitative results. One participant stated, "I'm not really sure of how soil is formed; maybe it's slow decomposition of organic material over time. I guessed C through process of elimination. A and B are too short of a time frame and soil wasn't here when Earth formed." Others simply stated, "I had no idea, so I guessed." Several students also admitted to guessing when asked about the depth of soil. Others discussed their experience with planting trees but weren't sure of the exact depth stating, "I think it's a few inches or maybe a few feet but it could also be as deep as a football field is long; but no deeper than that." Another participant believed soil to be several miles deep stating, "I thought about how deep the crust is and soil is part of the crust so it has to be several miles deep." The last item addresses porosity and the majority of students understand this concept. However, a few students selected B and in follow-up interviews explained their reasoning. One student stated, "The rocks in funnel A wouldn't pass through as quickly because the rocks are huge and they would absorb some of the water. The rocks in funnel C are small so the water would capture some of the rocks and pass through but not as quickly as the rocks in funnel B." The three items related to soils appear to confirm these above results, and many students appear to simply be posing their best guess.

EGGS Concept 11: ***Landforms result from the interplay between processes that create crust (plate movement, crust uplift, and sedimentary rock formation) and those that destroy crust (weathering and erosion). These interactions occur at a variety of time scales.***

Figure 27. Item Analysis for EGGS Question 27

Q27. How old are the Rocky Mountains?		
Response Labels	**Item difficulty**	**Item discrimination**
a. As old as Earth (formed about the same time)	0.12	
b. As old as most mountain chains on Earth (except the newest volcanoes)	0.73	
c. As old as dinosaurs	**0.12**	-0.09
d. As old as the United States Constitution	0.03	

Figure 28. Item Analysis for EGGS Question 28

Q28. In general, which direction do rivers flow?		
Response Labels	**Item difficulty**	**Item discrimination**
a. Downhill	**0.40**	0.48
b. North to south	0.22	
c. West to east	0.04	
d. Both B & C	0.34	

There is surprisingly little research on student's conceptual understanding of landforms. Francek's (2013) report on 500 misconceptions lists only karst topography when discussing landforms. Question 27 was devised to measure students' thinking about the variety of timescales encountered when learning geology. Our results show that 73% of students hold the misconception that all mountains are the same age. It should be noted that we find this near zero item discrimination to be acceptable because of the small number of students that answered this question correctly. Question 28 is adapted from research by Trend, Everett, and Dove (2000) who reported students believe rivers always flow north to south or west to east rather than downhill. Our results are consistent with Trend and colleagues (2000), with 60% of students suggesting rivers flow north to south and/or west to east.

When asking students to elaborate on their understanding of mountain ages, many students believe all mountains are around the same age but it appears students choose this answer by a process of elimination. One participant stated, "I know that all geologic features change over a long period of time so the answer couldn't be A (as old as Earth). I'm not sure how old dinosaurs are and the US constitution is too young. So the logical answer is B." In follow-up interviews, many students believe rivers flows north to south. Some participants utilized rivers close to their home stating, "In California, the Sacramento river flows north to south so I assume all rivers probably flow in that same direction. Other participants believe rivers flow west to east. One student accredited the stars stating, "The sun has no correlation to the direction but the stars rise in the east and set in the south [*sic*] so rivers probably run west to east." These two items appear to be working as designed.

CONCLUSION

In the service of establishing the validity and reliability of a tool to efficiently determine students' understanding of a broad consensus of important geology concepts, we administered the final version of the EGGS Exam of GeoloGy Standards to non-science majoring undergraduate students enrolled in introductory college science survey courses, and completed follow-up think-aloud interviews. In answer to a motivating question for this study, which geology misconceptions do introductory college geology students harbor?, the EGGS is successfully able to identify misconceptions described in much of scholarly literature surrounding geoscience education, in addition to identifying several new misconceptions.

Overall, 172 participants scored an average of 42% correct with a standard deviation of 0.014. The Cronbach's alpha was 0.69 and the average item discrimination was 0.34. Taken together with supporting interview data, we judge that the EGGS is a valid and reliable investment to efficiently elicit students' misconceptions. Appendix A provides a synthesized list of misconceptions aligned with the 11 most common conceptual ideas identified from an overlap of the national standards documents. Taken together, the results of this effort suggest that EGGS is now ready for wide-scale deployment in the geoscience education community, as one of a growing number of tools available to help faculty improve teaching and learning.

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Additional information can be found online at URL: http://www.caperteam.com/eggs

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APPENDIX

Synthesized List of Misconceptions Aligned with EGGS Conceptual Targets

Consensus Concept	Misconceptions (Frequency)
1. Earth's crust is broken into plates, which slowly move in relationship to each other, driven by convection currents in the mantle.	Earth's plates move apart at oceanic-continental convergent boundaries (15%) Tectonic plates are separate from Earth's surface (36%)
2. Atoms of different elements combine to make minerals, which combine to make rocks. Rocks and minerals are classified by on their chemical and physical properties.	Rocks are classified by density, texture, temperature, or chemical composition (94%) The construction and building materials, slate, marble, and granite, are not rocks (30%). An oil well is drilled halfway to Earth's center (18%); As deep as a football field is long (31%).
3. Earth materials take many different forms as they cycle through the geosphere. Rocks form from the cooling of magma, the accumulation and consolidation of sediments, and the alteration of older rocks by heat, pressure, and fluids. These three processes form igneous, sedimentary, and metamorphic.	Primarily, heat (17%) or chemical bonding (17%) causes sediment grains to stick together to form sedimentary rocks. Rocks form in the center of the Earth (not present in quantitative results; 17% of participants interviewed). Earth's crust found near mid-oceanic ridges is generally older than crust found near North America (31%) North America was discovered last; therefore, the rocks in North American are younger than the rocks in Africa (not present in quantitative results; 50% of participants interviewed)
4. Earth's rocks allow us to reconstruct Earth's history, giving both relative and absolute dates.	People and dinosaurs co-existed (8%). Life appeared when Earth formed (14%). Dinosaurs died out about 5,000 years before peopled appeared on Earth (26%).
5. Fossils provide evidence about the types of organisms that lived long ago and the nature of the environments at that time.	Most species of living things alive today have existed since the time life began, but new ones have appeared too (37%).
6. Earthquakes, mountain building, volcanic activity, and ocean floor features occur at plate boundaries as the result of plate movement.	Volcanoes are typically observed along the margins of the Pacific and Atlantic Oceans (26%), mostly on continents (9%), or mostly on islands (15%). Volcanoes and earthquakes are studied together because both are caused by pressure pushing up from underneath (41%). Colliding plates under continents are most likely to produce volcanoes (70%).
7. The Earth has a layered structure with a dense metallic core, hot convecting mantle, and a brittle crust.	The most dense part of Earth is near the South pole (7%) or above the South pole but below the center of Earth (19%). The very center of the Earth is mostly made of a combination of gases, liquids, and solids (32%).
8. Earth's interior is heated primarily by radioactive decay and gravitational energy.	The innermost parts of the Earth are incredibly hot. This high temperature mostly comes from energy leftover from the not-yet-cooled Earth from its formation (38%). Unable to calculate half-life (75%).

Synthesized List of Misconceptions Aligned with EGGS Conceptual Targets (continued)

9. Rocks are chemically and physically weathered into smaller pieces, which are transported (eroded) by gravity, water, ice, and wind.	Water can make a valley deeper by carrying loose rocks away from the valley, but water cannot break off pieces of rock form the solid rock layer of a valley (18%). Valleys can get deeper, but water cannot make them deeper (16%). Water cannot dissolve rock (15%). Although water can dissolve rock and can move dissolved rock material to a new location, dissolved material cannot become solid rock (30%).
10. Soil is formed by weathered rocks and decayed organic materials.	Soil is as old as Earth—it formed about the same time (22%). The depth of soil is nearly to the center of Earth (9%).
11. Landforms result from the interplay between processes that create crust (plate movement, crust uplift, and sedimentary rock formation) and those that destroy crust (weathering and erosion). These interactions occur at a variety of time scales.	Rivers flow north to south (22%). Rivers flow north to south and west to east (34%).

Science Survey

EGGS161205

This is a voluntary survey to help us improve and focus this class. Your answers nor your participation impacts your grade.

Always select the BEST answer.

---

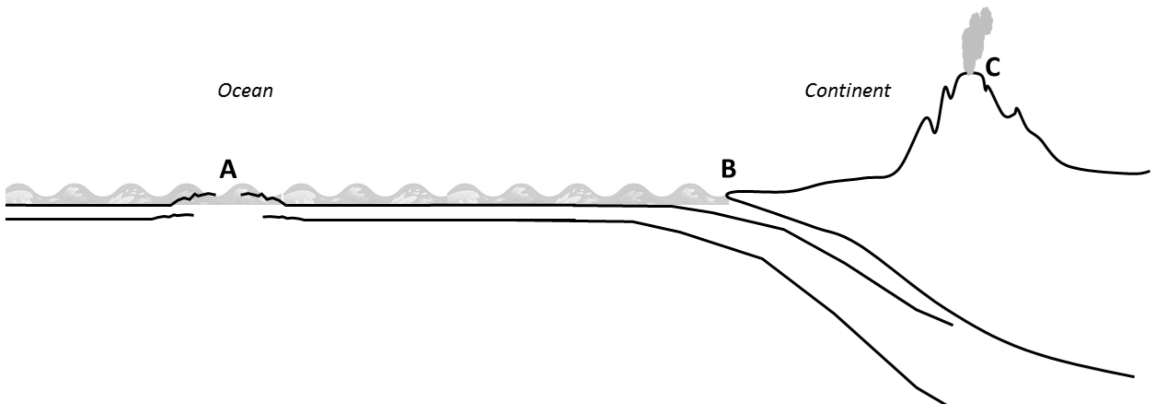
1. About how far do Earth's continents—and plates they ride on—move in a single year?
   a. A few inches
   b. A few hundred feet
   c. A few miles
   d. Continents and plates do not really move

2. Which of the following construction and building materials is ***NOT*** actually a rock?
   a. Slate
   b. Brick
   c. Marble
   d. Granite

3. How deep is an oil well drilled?
   a. As deep as a football field is long
   b. About a mile
   c. Halfway to Earth's center
   d. To Earth's center

4. We can best determine the environment in which lava or magma solidifies and becomes a rock by using the rock's
   a. density.
   b. mineral grain sizes.
   c. texture.
   d. temperature.
   e. chemical composition.

Cross-section illustrating Earth's crustal plate boundaries showing oceanic crust and continental crust (*not to scale*)



5. Which letter on the diagram above illustrates a location where Earth's plates are moving APART?
   a. A
   b. B
   c. C
   d. Both locations A & B are moving apart

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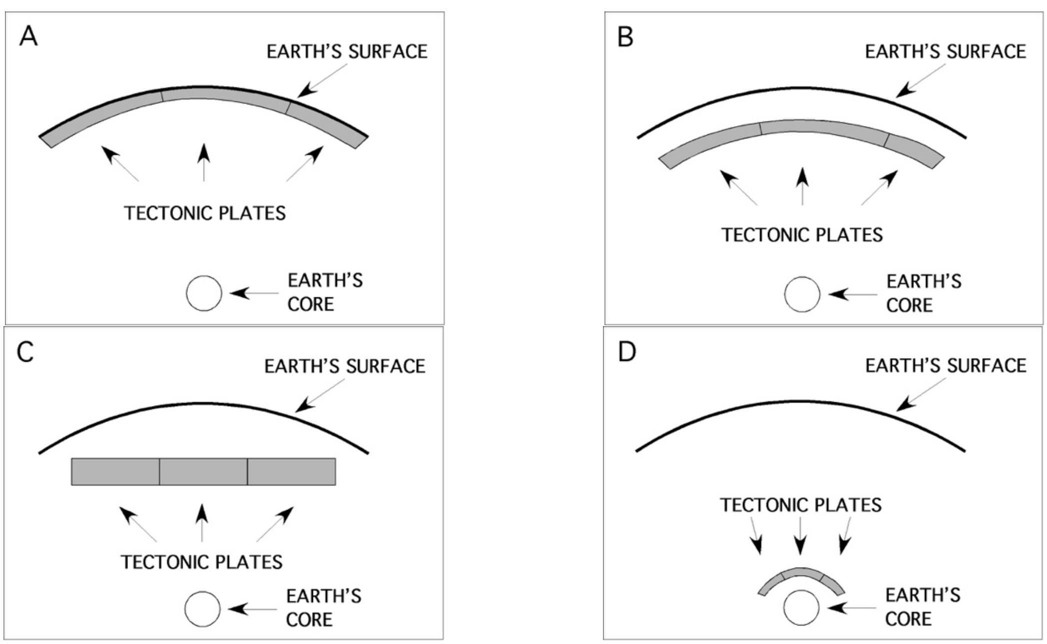
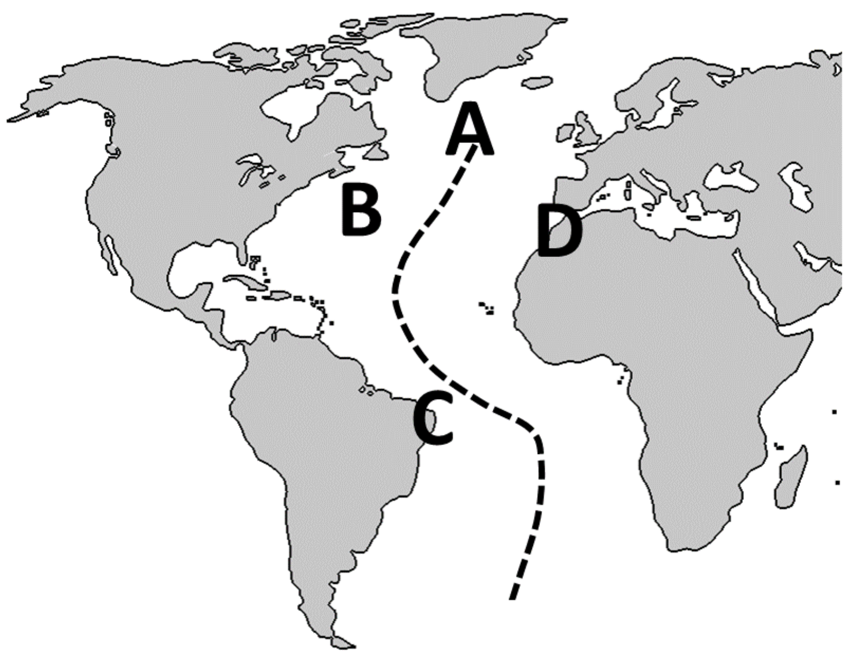
6. Scientists often talk about Earth's tectonic plates and their role in mountain formation, volcanoes, and earthquakes. Which of the following figures most closely represents the location of Earth's tectonic plates?



Item #6 is adapted from GCI*v.3*, Libarkin, J. C., & Anderson, S. W. (2005). Assessment of learning in entry-level geoscience courses: Results from the Geoscience Concept Inventory. *Journal of Geoscience Education*, *53*(4), 394-401, funded by NSF 0127765, 0350395, 0717790, 0717589

7. Primarily, why do sediment grains stick together to form sedimentary rocks?
    a. Pressure
    b. Heat
    c. Erosion
    d. Chemical bonding

Use the drawing below to answer the next <u>two</u> questions.



8. Imagine rock samples were gathered from Earth's crust in each of the marked locations. Rank the collected rock's ages in order from youngest to oldest.
    a. YOUNGEST ← A < B < C < D → OLDEST
    b. YOUNGEST ← D < C < B < A → OLDEST
    c. YOUNGEST ← A < C < B < D → OLDEST
    d. YOUNGEST ← B < D < C < A → OLDEST
    e. YOUNGEST ← A < B < D < C → OLDEST

9. Compared to Earth's crust at location A, the crust at location B is
    a. old, cold and thick.
    b. dark, dense, and hot.
    c. dense, cold, and young.
    d. dense, thick, and cold.

---

10. Which of the following best describes the relationships between humans (people) and dinosaurs?
    a. People and dinosaurs co-existed for about 5,000 years
    b. People and dinosaurs co-existed for about 500,000 years
    c. Dinosaurs died out about 5,000 years before people appeared on Earth
    d. Dinosaurs died out about 5,000,000 years before people appeared on Earth
    e. Dinosaurs died out about 50,000,000 years before people appeared on Earth

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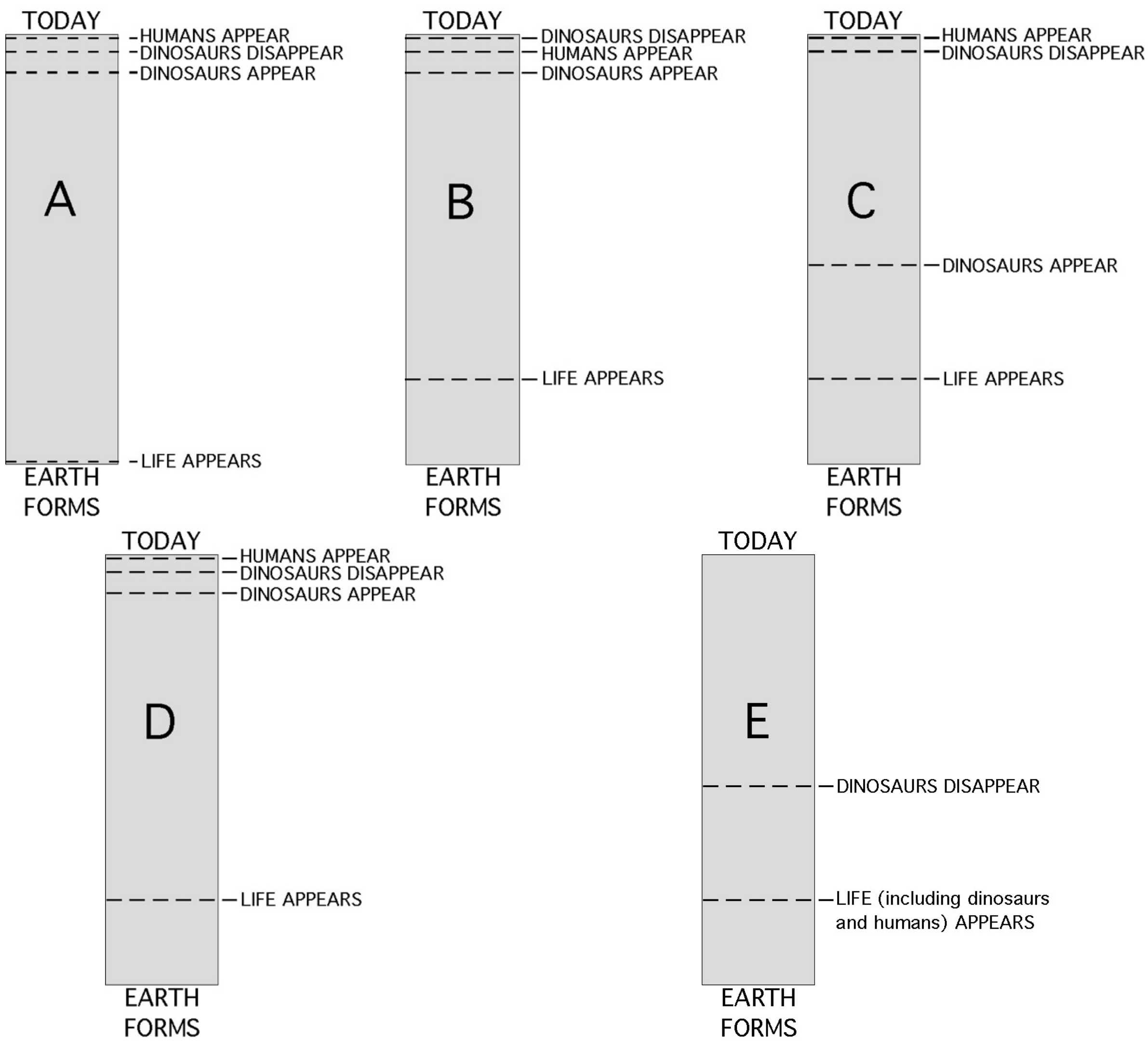
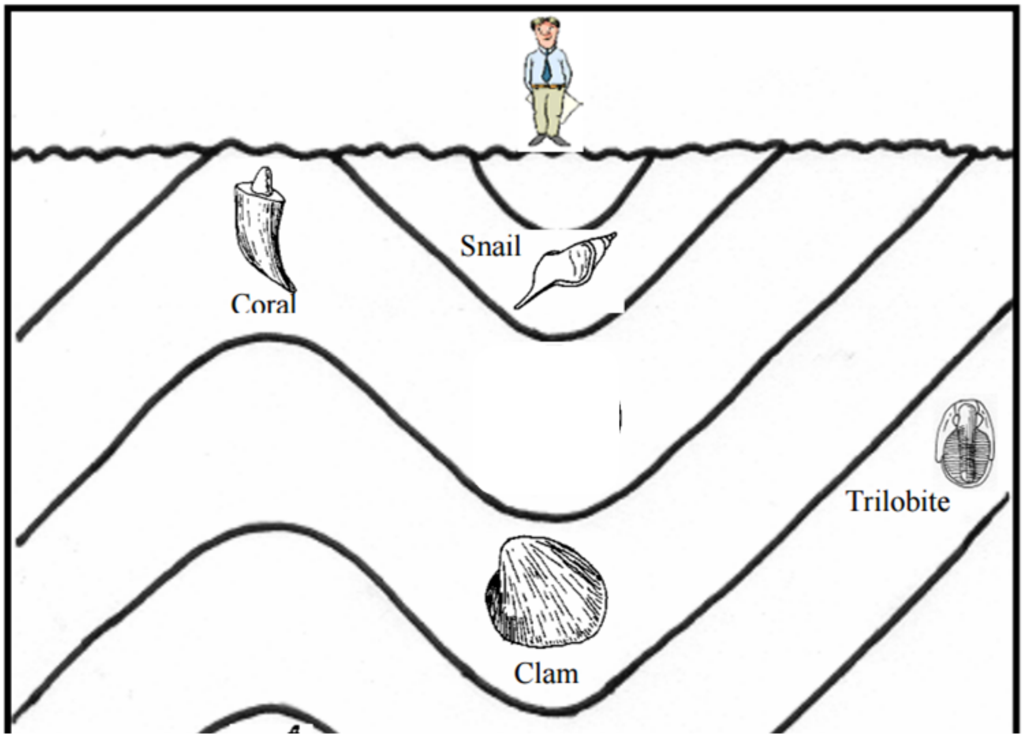
11. Which of the figures below do you think most closely represents changes in life on Earth over time?



Some items are adapted from GCI*v.3*, Libarkin, J. C., & Anderson, S. W. (2005). Assessment of learning in entry-level geoscience courses: Results from the Geoscience Concept Inventory. *Journal of Geoscience Education*, *53*(4), 394-401, funded by NSF 0127765, 0350395, 0717790, 0717589.



Item adapted from Dodick, J., & Orion, N. (2003). Measuring student understanding of geological time. *Science Education*, *87*(5), 708-731.

12. A geologist in the diagram is standing on marine sedimentary rock containing fossils. What is the order of fossils according to their age from oldest to youngest?
    a. OLDEST ← trilobite, clam, coral, snail → YOUNGEST
    b. OLDEST ← clam, trilobite, snail, coral → YOUNGEST
    c. OLDEST ← coral, clam, snail, trilobite → YOUNGEST
    d. OLDEST ← clam, trilobite, coral, snail → YOUNGEST

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13. Most species of living things alive today
    a. have existed since the time life began.
    b. have existed since the time life began, but new ones have now appeared too.
    c. did not exist when life began on Earth.

14. The scientific term "fossil" refers to
    a. remains of once living things.
    b. remains of living things AND traces, like preserved footprints.
    c. once living things that are now extinct and no longer live anywhere on Earth.

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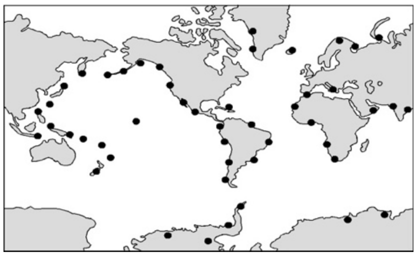
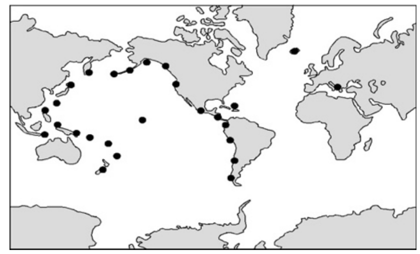
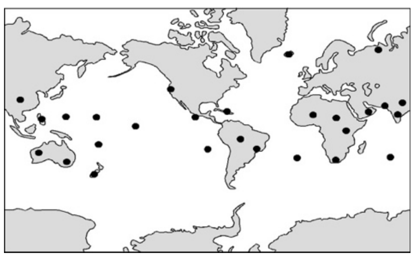
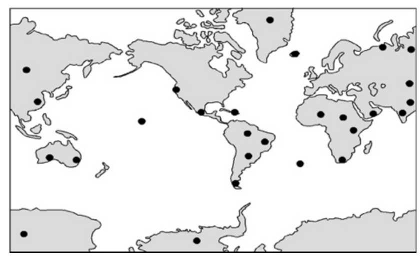
15. The maps below show the position of the Earth's continents and oceans. The ● symbols on the maps mark the locations where **VOLCANIC ERUPTIONS** occur on land.

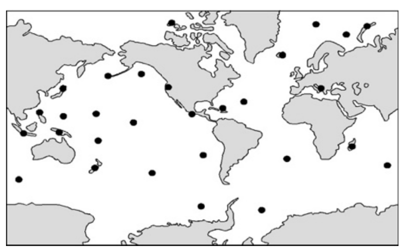
    Which map do you think most closely represents the places where these volcanoes are typically observed?


A. Mostly along the margins of the Pacific and Atlantic Oceans


B. Mostly along the margins of the Pacific Ocean


C. Mostly in warm climates


D. Mostly on continents


E. Mostly on islands

Item is adapted from GCI*v.3*, Libarkin, J. C., & Anderson, S. W. (2005). Assessment of learning in ntry-level geoscience courses: Results from the Geoscience Concept Inventory. *Journal of Geoscience Education*, *53*(4), 394-401, funded by NSF 0127765, 0350395, 0717790, 0717589

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16. Why are volcanoes and earthquakes often studied together?
    a. Earthquakes force lava upwards
    b. Earthquakes cause volcanoes
    c. Both occur at plate boundaries
    d. Both are caused by pressure pushing upward from underneath

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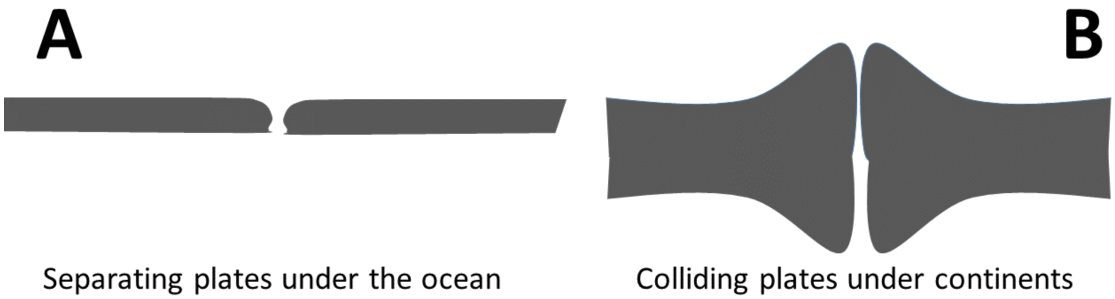
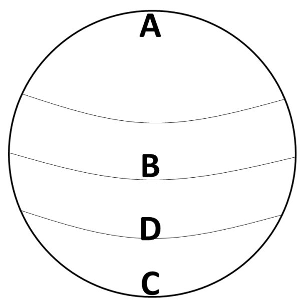
17. Which of the plate boundaries shown below as cross-sections are most likely to produce volcanoes?





18. The most dense part of Earth is near the point
    a. North Pole
    b. Earth's center
    c. South Pole
    d. above South Pole, but below center of Earth

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19. The very center of Earth is mostly made of
    a. gases.
    b. liquids.
    c. solids.
    d. a combination of gases, liquids, and solids.

20. Most scientists think that the inner most parts of Earth are incredibly hot. This high temperature mostly comes from energy
    a. emitted from radioactive decay.
    b. leftover from the not-yet-cooled Earth from its formation.
    c. from the Sun.
    d. due to Earth's gravity.

21. If a 5 kilogram radioactive rock has a half-life of 50,000 years, this means that in 50,000 years, the rock will be
    a. 1 ¼ kilogram.
    b. 2 ½ kilograms.
    c. 5 kilograms.
    d. 10 kilograms.

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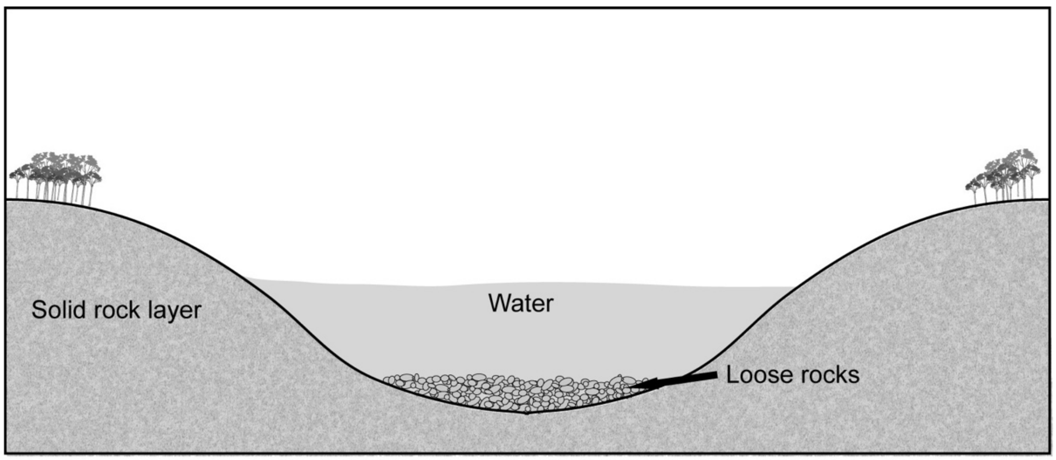
22. In the cross-section of a river valley shown below, there are loose rocks on top of a solid rock layer. Can water make the valley deeper?
    a. No, valleys do not get deeper.
    b. No, valleys can get deeper, but water cannot make them deeper.
    c. Yes, water can make the valley deeper by breaking off pieces of rock from the solid rock layer of the valley and by carrying loose rocks away from the valley.
    d. Yes, water can make the valley deeper by carrying loose rocks away from the valley, but water cannot break off pieces of rock from the solid rock layer of the valley.



Items #22 & 23 are adapted from AAAS Project 2061 Science Assessment Website (n.d.) at http://assessment.aaas.org/

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23. Can water dissolve rock material and move the dissolved material to a new location, and deposit the dissolved rock material as solid rock?
    a. Yes, water can dissolve rock, move dissolved solid rock material to a new location, and deposit dissolved rock material as solid rock.
    b. No, although water can dissolve rocks, water cannot move dissolved rock material to a new location.
    c. No, although water can dissolve rock and can move dissolved rock material to a new location, dissolved material cannot become solid rock.
    d. No, water cannot dissolve rock.

24. About how old is most of the soil near the location where you live?
    a. Tens to 100s of years old
    b. Thousands of years old
    c. Millions of years old
    d. As old as Earth—it formed at about the same time

25. About how deep is the soil where you live?
    a. A few inches, or a maybe a few feet, deep
    b. As deep as a football field is long or more
    c. Several miles deep
    d. To nearly the center of Earth

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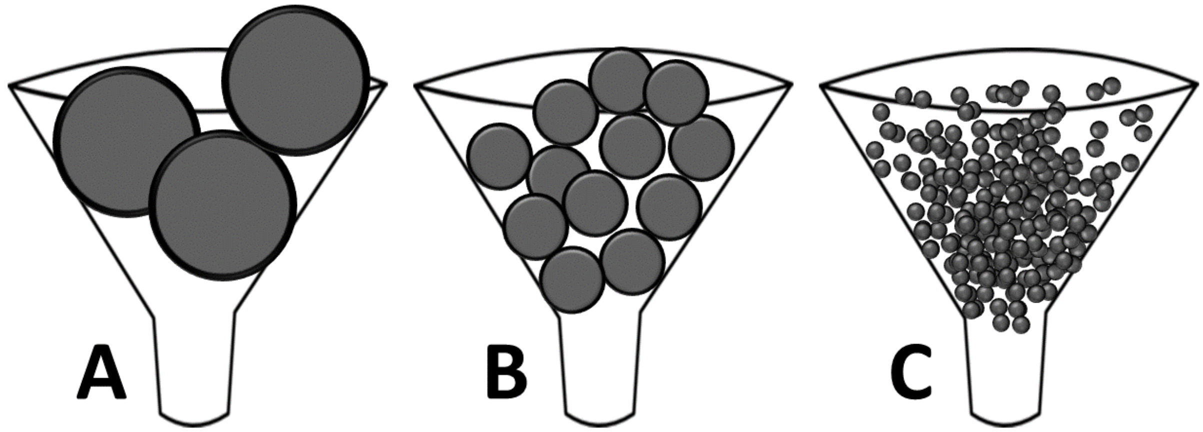
26. The figure below shows three funnels holding 10 kilograms of different sized rocks. In which case will water poured into the top pass through it MOST QUICKLY?



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27. How old are the Rocky Mountains?
    a. As old as Earth (formed about the same time)
    b. As old as most mountain chains on Earth (except the newest volcanoes)
    c. As old as dinosaurs
    d. As old as the United States Constitution

28. In general, which direction do rivers flow?
    a. Downhill
    b. North to south
    c. West to east
    d. Both B & C above

NOTES