The Living Earth

Inviting Students into the World of Scientific Research through Seismology

By Michael Barnett, Alan Kafka, Anne Pfitzner-Gatling, and Eugene Szymanski

In an introductory geoscience course, we combined various elements of seismology—such as seismographs, seismograms, simulation of earthquake processes, and data analysis—with open-ended problem solving to support preservice elementary teachers in understanding Earth science concepts.

Introductory science courses have a crucial role in forming elementary teachers' attitudes toward and understanding of science. Because some experts do not believe that this preparation is adequate, they are calling for reform in the content and teaching of introductory undergraduate science courses (NRC 2001). The proposed reforms call for the development of more inquiry-driven undergraduate science education and suggest the development of hands-on laboratory and field activities as primary strategies to improve undergraduate science courses (NRC 2003).

With these goals in mind, we developed a yearlong interdisciplinary introductory geoscience course designed to engage prospective elementary teachers in inquiry-based learning. The course uses seismology as a medium for teaching a wide variety of science topics, and it combines various elements of seismology such as seismographs, seismograms, simu-

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lation of earthquake processes, and data analysis with open-ended problem solving.

Seismology and Learning

To determine the current state of students' knowledge of earthquakes, we searched the Duit (2004) misconception bibliographic research database. Surprisingly, only four of the 5,956 studies directly addressed student understanding of earthquakes, with only two more studies addressing the effect of instructional strategies on student understanding of earthquakes. A review of this small set of studies suggested that many students and adults do not understand the theory of plate tectonics and the causes for earthquakes, and they often believe that earthquakes are caused by either unrelated natural phenomena such as weather or by supernatural forces.

For example, Tsai (2001) interviewed 52 fifth-grade students in Taiwan after the island experienced an earthquake. The interviewer found that students:

- believed that supernatural forces cause earthquakes,
- relied upon cultural myths to describe the underlying causes of earthquakes, or
- believed that a radical change in gravity is the cause of earthquakes.

Tsai also found that students got their information about earthquakes from television news, newspapers, friends, parents, and lastly their teachers.

In a similar study, Ross and Shuell (1993) interviewed 91 elementary students from New York and Utah and found that most students struggled to explain what an earthquake is and believed that earthquakes are caused by the Sun. Regarding adults' ideas, Turner, Nigg, and Paz (1986) interviewed 1450 adults in California and found that only 53% could adequately explain the causes of earthquakes and many believed in earthquake myths such as "earthquake weather" as a precursor of increased seismicity.

In another study, Barrow and Haskins (1993) interviewed 186 college students who were enrolled in an introductory geology course and found that students:

- generally equated volcanoes with earthquakes,
- believed that earthquakes only occur along plate boundaries, with no chance of intraplate earthquakes,
- lacked a broad understanding about the theory of plate tectonics, and
- obtained much of their information through television news reports and newspapers.

The course we designed is the first semester of a yearlong sequence that satisfies the science core requirement at Boston College; it was specifically designed for future elementary teachers and consists of two components. The first component is a traditional lecture format that meets for approximately two hours each week, and the second component is a lab that meets every week for one to one-and-a-half hours. We had 75 students enrolled in the course and had three lab sections. Because the lecture was more traditional, we focused on changing the laboratory and developing inquiry-oriented research projects that would improve our future elementary teachers' scientific content and process knowledge.

Driving Questions

When designing project-based activities, it is important to provide driving questions that focus students' activities and give them insight into the type of questions and investigations that may be useful in solving the problems that arise during these classroom activities (Blumenfeld et al. 1991). With this in mind, our overall driving question for the laboratory portion of our course was: "Is it possible to predict the location, time, and size of future earthquakes?" To this end we asked students the following set of questions at the beginning of the course:

- What do you predict will be the number of earthquakes of magnitude 6 or greater that will occur on the Earth during final exams week? How about magnitude 5 or greater? Where will they occur?
- Do you predict that there will be an earthquake of magnitude 7 or greater during final exams week? If so where will it be located?

These questions provide a framework for lab projects and emphasize that a primary goal of science is to make predictions about the future.

Project 1: Earthquake detection: Build your own seismograph. It is truly fascinating that it is possible to record earthquakes at great distances using seismographs. In fact, it doesn't take a particularly complex seismograph to record earthquakes from across the globe. In this course, we use a simple, inexpensive seismograph (the AS1 seismograph, available online at *www.amateurseismologist.com*) that we operate as part of the Boston College Educational Seismology Project. Throughout the course, students examine seismograms recorded by the AS1 to better understand the various aspects of seismology covered in the course. However, seismographs are a rather "black-boxed" scientific instrument. Before taking this course, most students had never seen a seismograph and had little appreciation of how they detect earthquakes.

In this project, students are given a wide range of materials (e.g., tape, straws, paper-towel rods, glue, and rubber bands) and are instructed to build an instrument that will detect motion. Although they see the AS1 as part of the course introduction, we do not spend a lot of time discussing how it operates until after this lab exercise is completed, and we hide the AS1 from view during this lab.

We don't give students detailed directions regarding how a seismograph works because we want them to work from first principles to determine what attributes a seismograph should have to detect motion. In doing so, students primarily focus on building a device that only detects motion. After giving students approximately 20 minutes to plan and develop their initial ideas, the teaching assistant shows the class a picture of one of the first seismographs produced by Chang Heng of the Han Dynasty in AD 132.

Heng's seismograph was a large bronze urn with eight dragon heads gazing outward in eight directions. Each dragon held a ball in its mouth. Around the base of the urn, under each dragon, sat a frog with its mouth open and a delicate inverted pendulum was hidden in the urn. The slightest seismic ripple moved the pendulum and tapped a ball into one of the frog mouths. Knowing which frog had been fed, it was possible to tell the direction of the quake but not the size or the time of the earthquake.

Like Heng, most student groups construct instruments (Figure 1) that can roughly determine an earthquake's direction and "size" (i.e., how hard the table on which their instrument is sitting is bumped). Once they achieve this level of success, most student groups conclude that they are done. However, we point out that their instrument also has to determine an earthquake's duration and time of occurrence. We continue to challenge students to consider how to design an instrument that does more than just detect motion and direction—it should also determine the magnitude of motion and the time it occurs.

FIGURE 1

Students designing and constructing their own seismograph.

Photo courtesy of the authors

After additional discussion and planning, most student groups hit on the idea that they need their seismograph to mark or document the motion's magnitude. Most groups recall the historical ball-and-drum seismographs in which a pen was used to mark paper on a rolling drum of paper. As students formulate their ideas, we show them a traditional ball-and-drum seismograph and describe its functioning. Students continue to work on their seismographs, and most groups realize the difficulty in designing an object that can detect motion, determine its magnitude, and record the time the motion began and ended. This challenge was noted in the following student lab notebook reflection regarding their design process and their prior knowledge of seismographs:

None of us really knew how seismographs work. We suspected that they work by having something marking on a scrolling piece of paper and when the whole device is shook by an earthquake it detects the shaking and marks it in some way. In building our seismograph, we first tried to build a device that would tell us which way the table was pushed. We did that by using marbles on top of a paper towel rod and a plate. This design was similar to Heng's design. We found it more difficult to figure out how to change our design so we could determine how much the table moved. Using the Richter scale as a model, we developed our own scale—if five marbles fell, then we had a strong "earthquake," and if three fell, then it was a "moderate" earthquake. We couldn't, at least with the provided materials, modify our design to detect the time at which the "earthquake" occurred. We tried to come up with a model similar to the drumlike seismograph but we couldn't figure out how to make it work. This was a fun and difficult activity, but I learned a lot from it.

In short, this project is problematic for students because there is no right answer, and most students have only seen pictures of seismographs and do not understand their functioning. However, through their struggles (and in some cases frustrations) to construct a realistic seismograph they come to appreciate the difficulties that scientists and engineers have in designing viable instruments to detect earthquakes.

Project 2: Earthquake tracking: Data-driven inquiry. This project was modeled after an epicenter

FIGURE 2

Earthquake tracking for one week (September 8–14, 2003), one month (September 8–October 7, 2003), and for the entire semester (September 9–December 7, 2003).

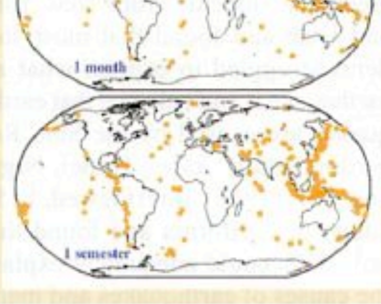
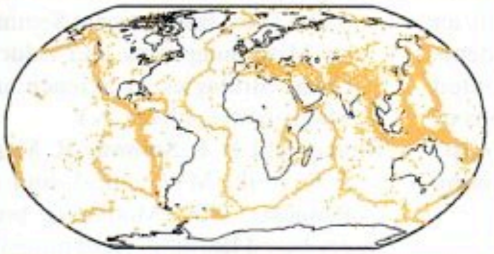


FIGURE 3
Global earthquake activity (NEIC, 1973–2002, magnitude 5).



plotting exercise described by Braile and Braile (2001), which provides a simple yet effective way for students to directly experience the concepts underlying earthquake activity and plate tectonics. Each week, a group of students is assigned to plot on a map of the Earth all earthquakes of magnitude (m) 5.0 or greater that were reported for that week by the National Earthquake Information Center (NEIC, available online at *http://neic.usgs.gov/*).

As the semester progresses, students construct a cumulative plot that eventually includes all earthquakes ($m \geq 5$) that occur during the entire semester. Figure 2 shows the results for one week, one month, and a cumulative plot for the entire semester. As students progress through this activity, they initially observe that the pattern of epicenters appears to be random. After about a month, however, the "Ring of Fire" around the Pacific begins to emerge from the scatter; and by the end of the semester, other plate boundaries become clearer.

The results for 30 years are shown in Figure 3 for comparison. Thus, the relationship between earthquakes and plate tectonics begins to emerge through a semester's worth of monitoring. This experience in itself is valuable for students because they use real data to distinguish earthquake patterns. However, the primary aim of this activity is that it provides the framework for one of the major questions that the students explore, namely, is it possible to predict when an earthquake will occur?

Project 3: Earthquakes within reach. To help students understand the behavior of faults and the challenges of earthquake prediction, we leveraged an activity developed by Hall-Wallace (1998) to allow students to investigate the mechanics of the so-called "stick-slip" behavior of faults. The experimental apparatus (Figures 4 and 5) includes blocks of wood that are placed on a flat board and connected to a bungee cord and a rope wrapped around a hand crank. The geological motion of tectonic plates is modeled by slowly turning the crank, and earthquakes are modeled as events in which the block slips. Fault friction is modeled by moving different types of sandpaper between the brick and the board.

This project is open-ended, with multiple variables to be tested, including type of fault surface (i.e., fine, medium, or rough), the mass of the slider-block, the elastic behavior of the bungee cord, and the speed at which energy is added to the system. This problem does not have a single correct solution and supports students in collecting data and analyzing the relationships among variables to investigate whether there are any variable relationships that might suggest insight regarding how to predict the occurrence of earthquakes (or in this case "blockquakes").

Students are initially unsure as to why they are doing this project because they are certain that predicting earthquakes is impossible. At the start, our students would not think in terms of the interdependency of variables or in terms of making probabilistic predictions but more in terms of either identifying the right answer or assuming that this was just another "busy" lab.

Rather than having students determine what data to collect, we provide them with a predesigned data sheet to collect their own data so that they can focus on analyzing their data. We do not tell students what data to plot, but rather we ask them to examine their data carefully through the lens of their emerging theories to determine if they can identify relationships among variables.

FIGURE 4
Experimental apparatus for the "blockquake" laboratory project.

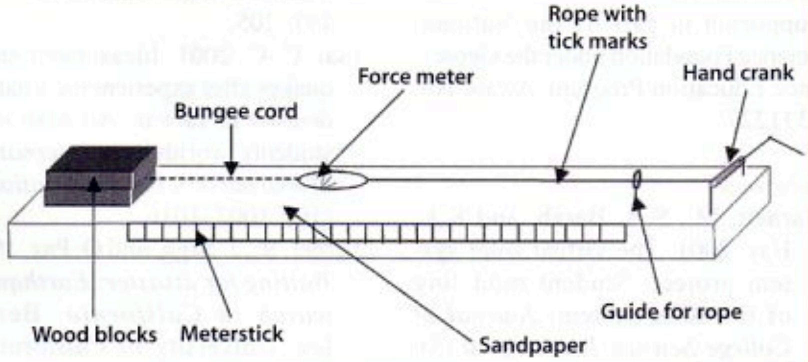


FIGURE 5
Students investigating whether an earthquake can be predicted using the "blockquake" apparatus.

Along the way, we ask students to continually develop hypotheses and to test their emerging theories in future experimental trials. However, as students redesign their experiments, surprises arise and opportunities for questioning and additional discussion emerge. While students design their own experiments, they are most engaged in questioning their own assumptions about earthquake prediction. For many of them, this is the first class in which they design their own experiments based on the outcomes of their previous experiments.

This project ends with students presenting their findings to one another; during their presentations it quickly becomes apparent that each group has collected a distinctive set of data and that understanding the experimental results requires additional discussion and rechecking of their own experiments. Our preservice elementary teachers have had little or no experience in designing experiments or exploring problems driven by curiosity. Yet, while working on this problem we have found that our students' curiosity and interest is stimulated by the knowledge that this is a real, unsolved research problem and that they are not working on a confirmatory laboratory exercise.

Project 4: Earthquake location. In this project, students are given the recordings of three real seismograms recorded by seismographs around the Northeast and expected to determine the epicenter of the earthquake. Through working with the data, students discover that while it is relatively straightforward to distinguish an eastern Massachusetts earthquake from one in western Massachusetts, there is considerable uncertainty regarding the precise location given the limited number of seismograms. Even with an earthquake that is well-recorded by professionals such as the New England Seismic Network (available online at *www.bc.edu/research/weston observatory*) and has a sophisticated computerized location algorithm, error estimates for the earthquake's location are plus or minus several kilometers. Thus, the problem of determining an earthquake's location is an excellent example of an inquiry-oriented exercise. Students use real data and are confronted with the same type of limitations of scientific inquiry that seismologists are confronted with in determining the location of an earthquake.

Discussion and Conclusions

Despite our success with this course, we want to make it more open-ended and do a better job of engaging students in inquiry-based learning. In this iteration of the course design, we use a combination of lecture and open- and close-ended problems. In essence, we want to ease students into a way of learning that many of them have not experienced before. We chose this approach based upon our previous experiences in redesigning introductory astronomy courses (Barnett, Barab, and Hay 2001) and because too dramatic a shift from traditional instruction to more inquiry-oriented instruction often leads to resistance by students (NRC 2003). Thus, we felt that a combined instruction approach consisting of diverse strategies was best. With that said, the question of how to weave different instructional methods together to best support our students in learning science, or at the very best, for students to leave our courses with the interest and desire to learn more on their own is still up for debate. ■

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