Using the AS-1 Seismograph for Laboratory Exercises in an Introductory Geophysics Course: Turning Seismic Moments into Teachable Moments

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INTRODUCTION

At Boston College, we teach a two-semester, first-year sequence in geology and geophysics for our majors. The course is divided into two parts, with the first semester focusing on geology and the second semester focusing on geophysics. Recently, we have also added some environmental topics in these courses, particularly in the first semester. In this paper, we describe laboratory exercises given in the second semester that are based on seismograms recorded on an AS-1 seismograph operating at Boston College. These lab exercises use topics in seismology to bring research experiences into a first-year undergraduate course and invite the students to think critically about what they learn in the course.

In our experiences with bringing seismographs into classrooms (at the high school, middle school, and undergraduate levels), we have found that what is often missing are exercises based on experiments that address real research questions. We have attempted to fill that gap with the lab exercises described in this paper. After a seismograph is successfully installed in a classroom, there is initial excitement over the fact that earthquakes from around the world are being recorded right in the classroom. At this point in the process, just the presence of an operating seismograph is, in itself, an enhancement to science education. At some point, however, this excitement fades, and the inevitable question arises, "OK, now that I have a seismograph in my classroom, what can I do with it (other than just watch it record earthquakes)?"

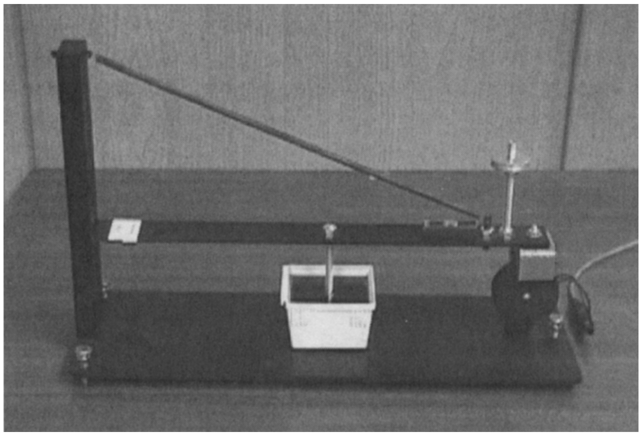
One major challenge is that of fitting a real research investigation into the curriculum. In high schools and middle schools, teachers usually have a set amount of time allocated to cover seismology, and then they are required to move on to other topics. In an undergraduate lab that meets for, say, two hours per week and is expected to cover many topics, it is difficult to fit in real research because research is inherently open-ended. One must, therefore, be willing to accept a flexible schedule and possibly not cover some "sacred" topics if the research experience is to be genuine. In spite of these challenges inherent to seismographs-in-schools programs, we were able to create a series of exercises to introduce the students to open-ended, inquiry-based scientific investigation.

The key to making this work is to choose a research question that is straightforward, is not a question for which the answer is the same for every school that uses these exercises, and is a question for which it is useful to know the answer. With these constraints in mind, the research question we chose is: "So, now that we have set up this seismograph, how often are we likely to record earthquakes with this particular seismograph in this particular location?" While this may seem at first glance to be a simple question, we have found that answering it actually requires some rather sophisticated critical thinking and problem-solving skills.

THE COURSE

The course is part of a two-semester sequence entitled "Exploring the Earth." Both semesters are required for our majors in either Geology or Geophysics, but only the first semester is required for our Environmental Geosciences majors. (The second semester is, however, highly recommended for environmental majors.) The course does not require any mathematics beyond what is necessary for admission to Boston College, yet it has a reputation for being somewhat harder (and more quantitative) than some other courses that satisfy the same distribution requirement of the environmental major. Not being required for all majors and being known as somewhat harder, the course often has very low enrollments. The course had four students each year during the past two years when these lab exercises were introduced. In the mid-1990's (when we had many more majors), there were times when two to three dozen students took this course. During the semester that this paper was being revised for publication, 21 students were enrolled in the course.

Low enrollment in this course is both a blessing and a curse. While it is a problem in terms of justifying our major programs to the administration, it made it possible for us to give the students the kind of attention necessary to conduct real research in the classroom. It also made it easier to encour-



▲ **Figure 1.** The AS-1 seismograph used for the lab exercises described in this paper.

age open-ended, curiosity-driven learning than would have been practical in a larger class. Our sense is that the lab exercises described here could work for up to about two dozen students but would be hard to implement for classes larger than that, unless significant changes were made to the exercises. So far, these exercises seem to be working well with the 21 students currently enrolled in the course.

THE LAB EXERCISES

The AS-1 seismograph is a simple, inexpensive, easy-to-set-up seismograph built by The Amateur Seismologist (Batten, 2002), which sells for $550. It is designed such that it is easy to see the inner workings of the mass-spring-coil system (Figure 1), which makes it natural to use for introducing other topics beyond seismology as the course progresses, such as the physics of oscillating systems and the recording and analysis of scientific data. We use the *AmaSeis* software (Jones, 2002) to record and display the AS-1 data.

Throughout the course and the lab, we were faced with the usual trade-off between covering many topics in some general way versus covering one (or a few) topics in detail. Certainly, we erred on the side of teaching seismology in detail, but the topic of seismology does lend itself to introducing a fairly wide range of other topics, from plate tectonics to analysis of scientific data. There were exercises on other topics in this lab, including measuring the force of gravity at the Boston College campus, measuring the radius of the Earth using the method of Eratosthenes, estimating the average density of the Earth, and conducting earthquake hazard assessments based on the HAZUS software (FEMA, 2001). However, about two thirds of the semester's projects were on seismological topics and were based on the AS-1 seismograph described in this paper.

Earthquake Tracking

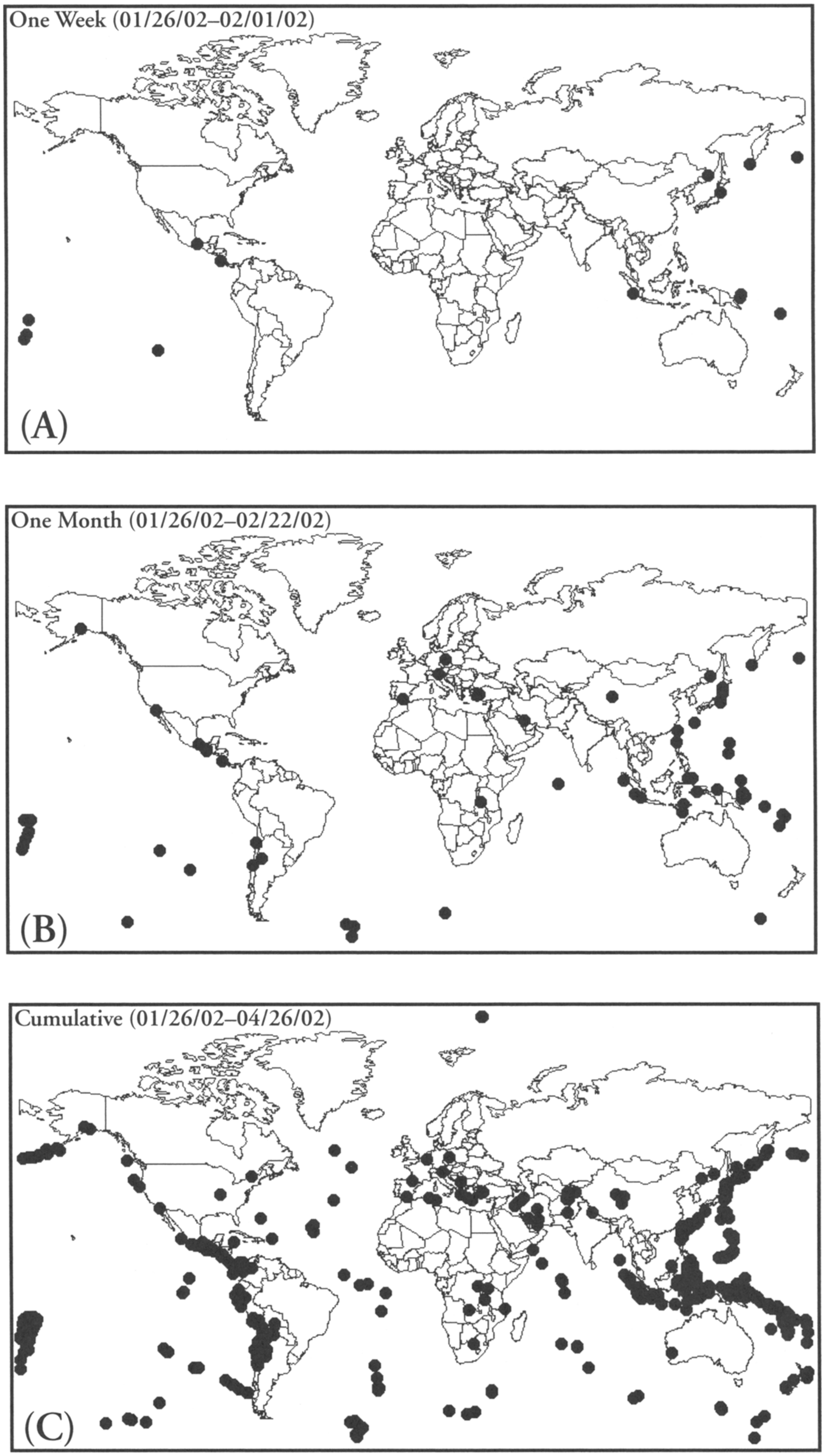
Several exercises lead up to the work on the research question, and the first of these is an earthquake-tracking exercise. This exercise is modeled after an epicenter-plotting exercise presented by Sheryl Braile at an IRIS Education and Outreach Workshop in 1998, which offers a simple yet effective way for students to directly experience some of the concepts they learn in the course. Each week a student is assigned to plot on a map of the Earth all earthquakes of magnitude 5.0 or greater that were reported for that week on the National Earthquake Information Center (NEIC) Web site (NEIC, 2002). As the semester progresses, the students construct a cumulative plot that eventually includes all earthquakes ($m \geq 5$) that have occurred during the entire semester. Figure 2 shows the results for one week and one month, as well as a cumulative plot for the entire semester. After about a week, the pattern of epicenters seems to be quite 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 begin to be defined by the seismicity. Thus, the relationship between earthquakes and plate tectonics begins to emerge with only a semester's worth of monitoring. The students enjoy watching the theory of plate tectonics unfold in front of them as the semester moves along. They are also quite engaged in trying to predict where the next earthquake will occur. This exercise is valuable in itself but also forms a good backdrop for our research question.

While they conduct this ongoing earthquake-tracking exercise, we introduce them to what is being recorded on our AS-1 by way of having them estimate magnitudes of earthquakes recorded on it. Some of the earthquakes that they plot in the earthquake-tracking exercise are also recorded on the AS-1, and thus they are now ready to obtain their own estimates of the magnitudes of those earthquakes.

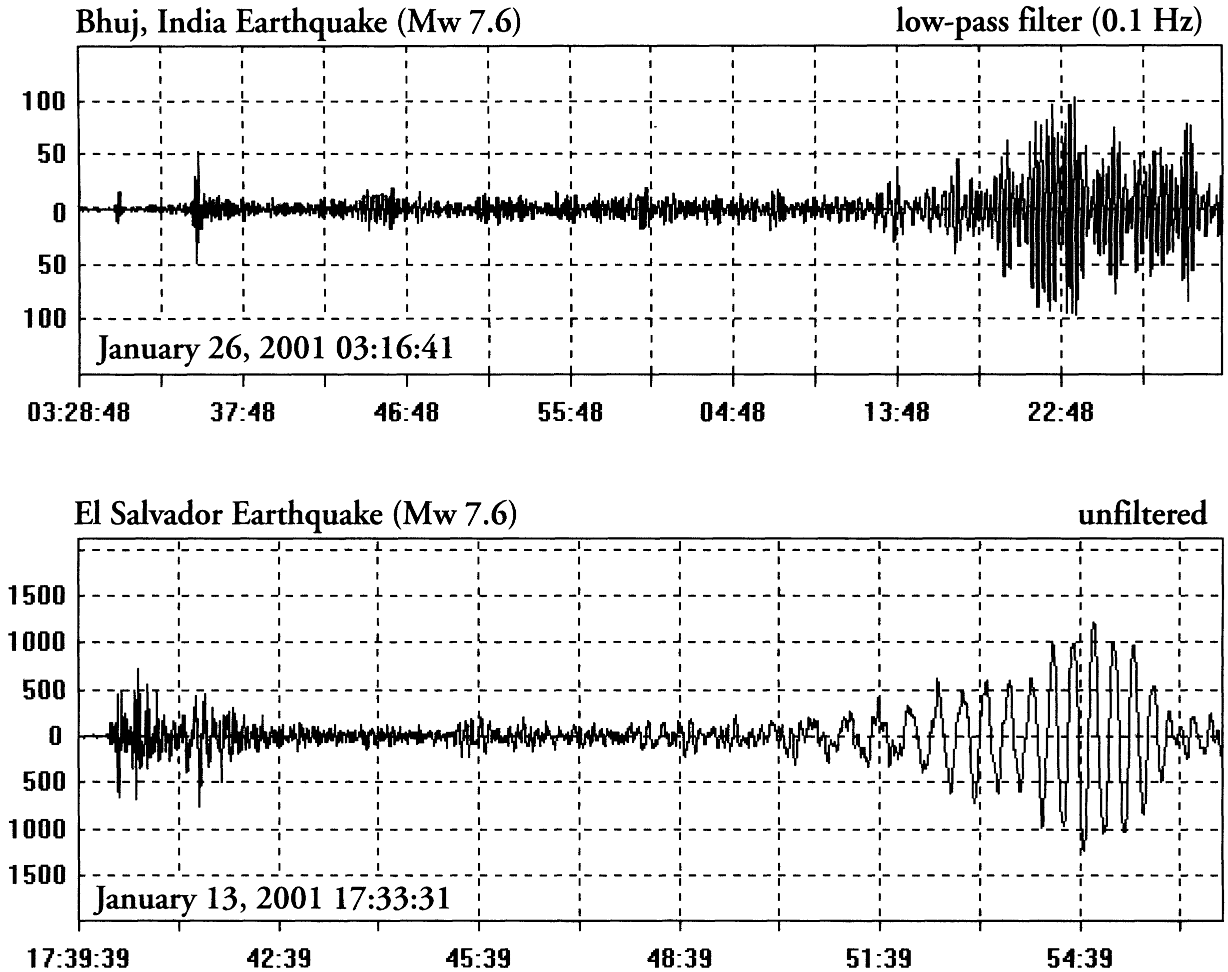
Estimating Magnitudes

In this exercise students estimate magnitudes of earthquakes from the AS-1 seismograms. In addition to the earthquakes they recorded during the semester, we also use significant and well recorded events archived from earlier times. For example, they estimate the magnitudes of the January 2001 El Salvador and Bhuj, India earthquakes from the seismograms shown in Figures 3 and 4. The objective of this exercise is for the students to learn about magnitude scales and measuring the size of earthquakes, and perhaps more importantly to gain experience with making measurements in scientific experiments.

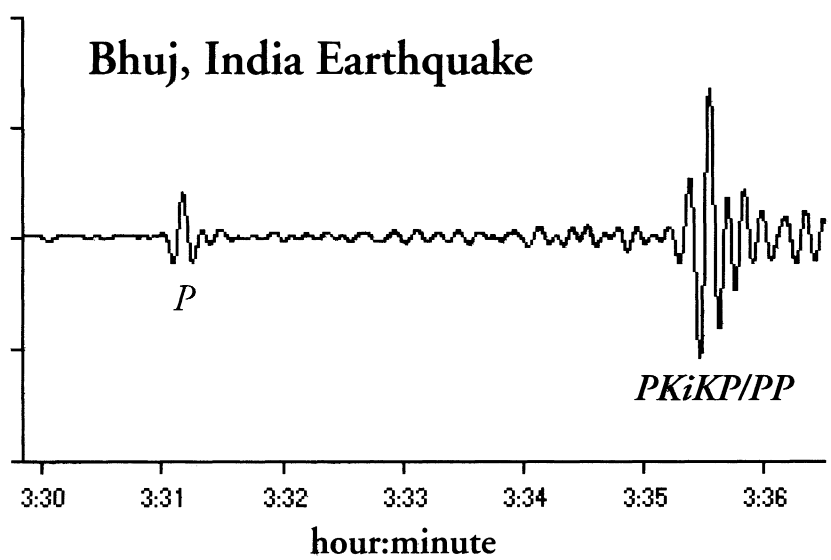
The students measure amplitudes and periods of *P* waves and surface waves, and correct the amplitudes for instrument response using the AS-1 magnification values given by Braile (2001). M_S and m_b estimates are calculated using these amplitude and period values and the formulas given in Braile (2001). For these measurements, we use the tool for extracting sections of seismograms that is part of *AmaSeis*, as well as a combination of three other seismogram display and analysis programs: *SWAP* (PEPP, 2002), *Wiggles* (Ammon, 2001), and *WinQuake* (Cochrane, 2002).



▲ **Figure 2.** Plots of the global distribution of earthquakes (magnitude 5 and greater) after (A) one week, (B) one month, and (C) one semester of monitoring.



▲ **Figure 3.** Seismograms of the Bhuj, India earthquake (above) and the El Salvador earthquake (below), recorded on the AS-1 seismograph operating at Boston College.



▲ **Figure 4.** *P*-wave section of the seismogram of the Bhuj, India earthquake recorded on the AS-1 seismograph operating at Boston College.

The Research Question: How Often Are You Likely to Record Earthquakes on Your AS-1?

This question was the basis for the investigation that the students worked on for the entire semester. We discovered that it was helpful to the students if we asked the question with the following, more specific wording: "If you operate the AS-1 at this location for one year, what is the average number of earthquakes that you are likely to record?"

To address this question, the students need to investigate how many earthquakes (of a given magnitude) are likely to occur across the globe in an average year, as well as where those earthquakes are likely to be located. They also have to investigate how this particular instrument senses and records earthquakes of a given magnitude and distance, with this particular siting of the instrument, at this particular location. To do this investigation, the students also need to think about plate tectonics, plate boundary versus intraplate earthquakes, magnitude scales, and earthquake recurrence relations. Furthermore, they need to estimate how stable the spatial and temporal patterns of earthquake occurrence are likely to be.

The answer to this research question is not just academic. As seen in the results below, we found that a simple AS-1 seismograph, without any complex siting requirements, even located at a school deep in the interior of a plate, can record earthquakes frequently enough to make it a useful instrument for classroom seismology. For the case of Boston College, we found that we would expect to record an earthquake on our AS-1 about twice a month. Knowing the answer to this research question should, then, help seismologists and teachers design better ways to integrate seismographs into the flow of their classroom experiences throughout the year, and should also help them decide on the cost/benefit of purchasing a more expensive seismograph (that would record earthquakes more often). Thus, the students are providing useful information to the research and education communities by doing this investigation.

When we first began the project, we asked very open-ended questions such as, "How would you go about investigating our research question?" This turned out to be more open-ended than the students could handle. They clearly needed (or at least wanted) more guidance. Although we found it disappointing that the students could not design this investigation on their own, we modified our approach by giving them specific instructions, such as, "Make a graph of epicentral distance versus magnitude. On that graph, plot the earthquakes that you recorded with one symbol and those that you didn't record with a different symbol. Then draw a line separating those earthquakes that you did record from those that you didn't record." (See Figure 5.)

The next step was for the students to try to estimate how many earthquakes are likely to occur at these distances and magnitudes in a year (on average), and thus how many earthquakes are likely to be recorded. We (naively) assumed that the students would make a connection between making this estimate and the results of the earthquake-tracking exercise, but they didn't really. We did not give them specific instructions on how to do this, and none of them was able to come up with and successfully implement a method that connects the number of earthquakes that occurred and their locations and magnitudes with the recording threshold in their graphs. An example of one of the student's results is shown in Figure 5. In the Discussion and Conclusions section, we address these issues in greater detail.

Earthquakes When They Happen: When Seismic Moments Become Teachable Moments

In addition to the more structured exercises described above, we also interrupted our planned lectures when an interesting earthquake was recorded during the day or two before a lecture or lab, and discussed our seismogram of that event. If the earthquake was widely reported in the media, this gave the students a direct sense of connection between their geophysics education and significant events in the world. If the event was not newsworthy enough that the students were aware of its size and location, then we would conduct an exercise in which the students tried to answer the following questions based on their one AS-1 seismogram: How far away was the earthquake? How big was it? Where might it be located? What might be the tectonic setting of this earthquake? By the end of the semester, the students (with some prompting) became fairly good at giving reasonable answers to these questions from visual inspection of the seismogram.

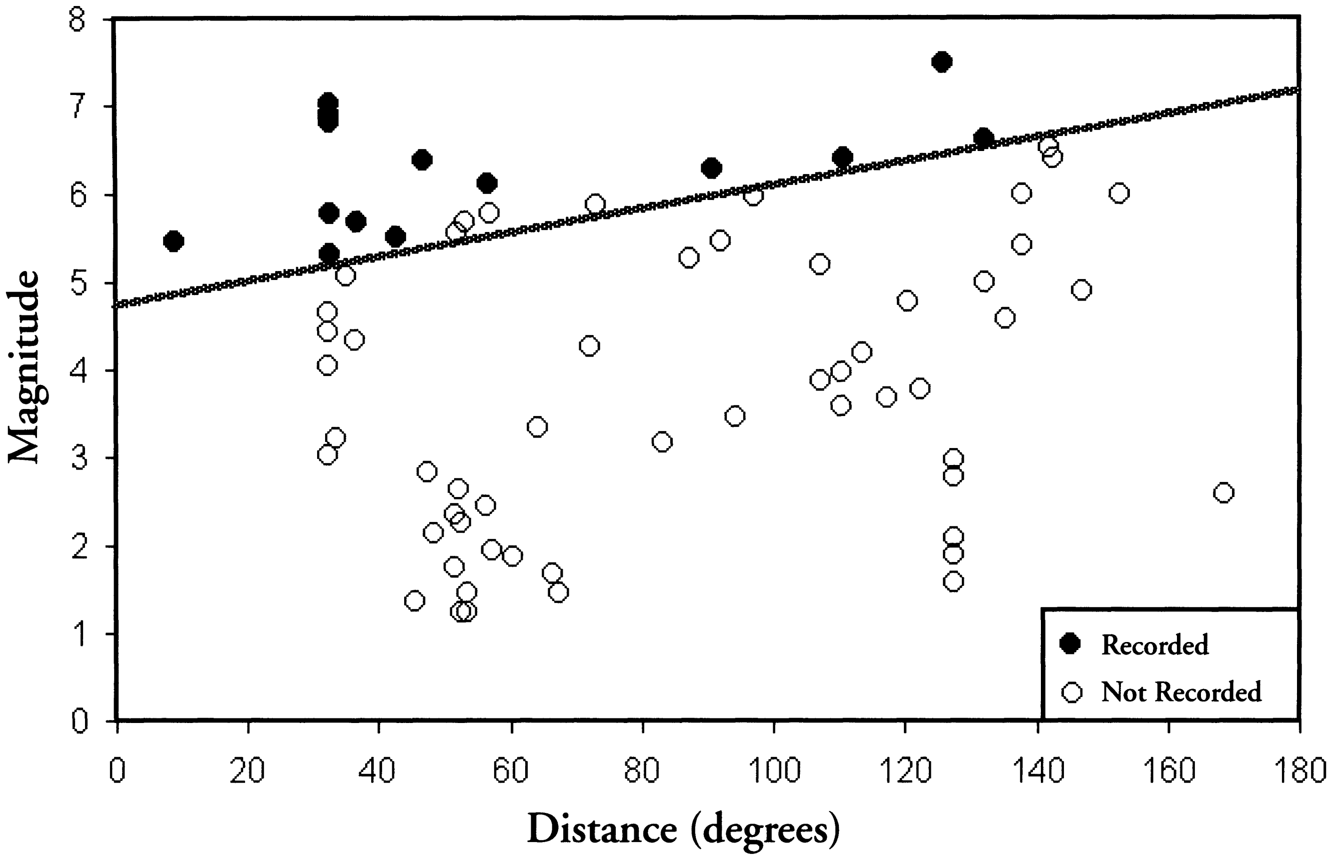
Although this was a valuable component of the course in terms of maintaining student enthusiasm for the lab exercises and reinforcing what they were learning during the semester, the downside was that we did not always cover the material that we expected to teach that day. We made the most of this downside by encouraging the students to take responsibility for learning the material on their own (and coming to us with questions if necessary).

DISCUSSION AND CONCLUSIONS

Having run these lab exercises for two years, we are convinced that they are very much worth doing. However, there are challenges and problems associated with them, and we are still learning. In particular, there was a significant gap between what we originally expected and what the students were ready for.

Regarding the magnitude exercises, the students did not seem to have any problem appreciating the fact that they got slightly different magnitude estimates than the NEIC, or that they got slightly different magnitudes than other students. This exercise seemed to be quite effective as a way to give the students experience with making scientific measurements in a realistic context.

Regarding the research question, however, much to our chagrin, most students had a hard time understanding what we were asking of them. We were disappointed to discover that when we asked students to design a scientific investigation in a completely open-ended way, they told us (very sincerely it seemed) that they had no idea what we were talking



▲ **Figure 5.** A student's plot of earthquake magnitude versus epicentral distance from Boston College. Filled circles represent earthquakes recorded on the AS-1 seismograph, and open circles represent earthquakes that were not recorded on the AS-1 instrument.

about. We found it to be a curious (and sobering) comment on the students' education that, although these were students with an expressed interest in science (and with high standardized test scores), the entire concept of conducting a scientific investigation was completely foreign to them! In the second year, we used a more directed, but still open-ended, approach, such as, "We suggest that you try plotting X versus Y ...." Although they were eager to follow instructions, rarely did the students plot anything other than what we told them to plot. In other words, the students did not seem to comprehend that plotting data is a *tool*; rather they saw it as just something you do to satisfy the teacher.

All of the students, of course, came up with plots similar to the one shown in Figure 5 (since they were all looking at the same earthquakes). Students independently drew their own lines separating recorded versus not recorded, and not surprisingly the lines were similar. How they proceeded once they had their plots varied. Most of the students abandoned the plot altogether and made their estimates empirically based on the number of earthquakes we recorded during the semester, and scaling that to a one-year time period. These empirical estimates ranged from about a dozen to about three dozen earthquakes recorded per year. This result is consistent with what we obtained when we solved the problem ourselves. Our solution was to count the number of earthquakes that occurred during the past twenty years in the magnitude and distance ranges that correspond to the region above the threshold line in Figure 5, and divide the sum by 20. The result we obtained was an average of 26 recorded events per year.

In each class of four students, one of the students did, indeed, develop an algorithm to use the threshold line and (having thought about the earthquake-tracking exercise) estimate the number of expected earthquakes corresponding to the region above the line during some number of years, and then divide by the number of years. Interestingly, however, both of those students obtained answers that were obviously not even close to being correct (about 300 recorded events per year in one case and about 1,200 per year in another case). Neither of these students even mentioned the fact that the results were very unrealistic because they implied that we would record an earthquake almost every day in one case and a few times a day in the other case. The AS-1 operating at Boston College doesn't even come close to recording earthquakes that often. So, some students were able to get the "right" answer using a very simple empirical method, and other students could reason through the problem theoretically but did not think it necessary to check their answers against reality!

In spite of these problems, the students seemed to enjoy this lab experience, and based on their exam performance seemed to learn a lot about seismology. They filled out a lab evaluation form at the end of the semester, and in both years the students gave favorable scores and comments about these laboratory exercises. We conclude that these kinds of exercises, based on analyzing real data, are very much worth doing. We must realize, however, that young people do not necessarily arrive in college ready to grasp what it means to conduct a scientific investigation. In fact, this is precisely why we think that these types of research-based lab experiences are vital.

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