A Comprehensive Stream Study Designed for an Undergraduate Non-Majors Course in Earth Science

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ABSTRACT
Science courses for students not majoring in science present unique teaching challenges to educators. Often non-science majors need help seeing the relevance of the course material and making connections between science and their own lives. One promising way to motivate these students and increase their interest in understanding is to integrate in an integrated lab/lecture format using inquiry-based methods. Such activities maintain a constant level of attention from the students by requiring them to collect their own data, analyze the data set, interpret their data, and prepare a class presentation of their findings. We are experimenting with a new set of science courses that are designed to be interdepartmentally staffed, to integrate aspects of mathematics, ecology, chemistry, and biology in an environmental theme, and to use guided-inquiry methods in a lab/lecture format. The interdisciplinary faculty team provides students with a diverse set of backgrounds and skills, and the interaction between instructors allows the students to observe the connection among the different sciences. The laboratory described below is a typical exercise drawn from our curriculum. We have modified a classic exercise in stream hydrology by integrating each of the scientific disciplines listed above in order to illustrate the advantages of interdisciplinary, guided-inquiry teaching methods. We find that an interactive approach greatly improves the student’s critical-thinking skills and stimulates scientific curiosity as compared to traditional lecture methods. While our new curriculum is facilitated by external funding and the commitment of our administration and science faculty, we believe that the exercise presented here is very flexible and can be undertaken by earth-science faculty in a variety of educational contexts.

Keywords: Education – geoscience; education – undergraduate; geology – teaching and curriculum; geology – field trips and field study; geochemistry; hydrogeology and hydrology.

Introduction
There is much talk nowadays about the poor educational preparation of the present generation of students and the alarming level of scientific illiteracy at all levels of society. Much of the blame lies with the fragmentary way science is taught in the schools and

is presented to the public in print and on television. It is as though an art lover had to be content to examine the Mona Lisa square inch by square inch, in no particular order, and across many months or years (Emiliani, 1992).

Science faculty at Hartwick College have identified the fragmentation of the math and science components of general education as a significant obstacle to understanding. We are working to improve the scientific literacy of our students through the development of a three-term (year-long) sequence of thematic, interdisciplinary courses in math and science for non-science majors. All Hartwick students are required to complete a minimum of three courses in math and science: one from the departments of Physics or Chemistry, one from Biology or Geology, and one from Mathematics or Computer and Information Sciences. The principal shortcoming of this approach is that students typically satisfy their science requirement with three courses selected from three different departments covering three different topics in three different years. This leads to significant fragmentation and lack of continuity in our students’ science experience. Students are led to believe that each different discipline of science addresses disparate issues and employs unique methodologies. Additionally, mathematics is not well integrated into the science curriculum for non-science majors. Math is not only taught in separate courses offered by a separate department – thus isolating it from the science that it was devised to describe – but even worse, most science courses offered to non-science majors have been specially designed by the instructors to be “math-free.” Our three-course sequence, offered as a package to first-year students, is designed to place mathematics in a scientific context in order to increase the students’ desire to learn math. Additionally, we believe that connecting several scientific disciplines by posing questions that are of interest to students will motivate them to pursue topics in science more enthusiastically. Students need to be active and engaged in their science courses. We use a combination of activities to not only give the student a better understanding of science, but also a better understanding of the importance of science in their lives and in their futures. These activities include “hands-on” experience with scientific equipment and data collection, with computer simulations and modeling and with field excursions.

Within the context of this integrated curriculum, we have developed a series of investigative laboratory
nd field activities. The theme that links each of our three courses is environmental science. In the fall semester we focus on the hydrosphere, in winter the atmosphere, and in spring the biosphere. While our curriculum is team-taught by faculty from the departments of Geology, Chemistry, Biology, and Mathematics, we believe that many of the inquiry-based exercises that we have developed for our students could easily be adapted by individual faculty members or teams of faculty for courses in a variety of fields such as introductory geoscience, ecology, or environmental chemistry. The activities could be especially helpful for faculty developing courses or curricula in Earth systems science. Inquiry-based learning—or what we prefer to call guided inquiry—shows great promise as an alternative to the lectures and “cookbook” labs of traditional science pedagogy (PKAL, 1991; Freedman, 1994; Allen and others, 1993; NRC 1996; Raloff, 1996; McNeal and D’Avanzo, 1997). We present a guiding question to the class, for example, “How do we assess the overall health of a river?” The students then brainstorm to develop the traditional pedagogy where the instructor selects the information freely given to the students. In contrast to the guided-inquiry approach immediately forces the students to ask questions and ask them in an order that makes sense to them. We feel that this process allows the students to better process and retain the subject material. This “free-form” instructional approach may strike fear in the hearts of some instructors, but it can be highly successful with some practice and preparation. Our experience demonstrates that students always hit upon workable procedures, especially when given additional guidance during the brainstorming process, and often develop novel and creative approaches.

A final component of our integrated curriculum is the combination of lecture and lab. By this we mean that we schedule long class periods (in our case, two hours) and make no formal distinction between “lecture” time and “lab” time. In fact, we lecture as little as possible (see Laws, 1991). This schedule better duplicates the conditions under which professional scientists work and provides us with a great deal of flexibility in terms of the sequencing of course activities. We don’t have to wait to perform a demonstration or go into the field; the activities can be carried out whenever they are most appropriate. Additionally, the courses have much greater continuity, as discussion or activities interrupted by the end of a class period resume immediately in the following session.

Example: An integrated stream study

We describe here one of the first investigative activities that our students are exposed to during the year, an integrated stream study. Numerous instructors have used some type of river study to introduce students to a particular discipline (for example, see Beiersdorfer and Haynes, 1991; NSF, 1994; Moore, 1995), but we have integrated aspects from several science disciplines (for example, biology, chemistry, hydrology, and mathematics) into one laboratory. River studies afford us an excellent opportunity to integrate aspects from each of these disciplines into one integrated lab/lecture exercise and allow us to teach students the benefits of mathematical analysis (Figure 1). The students can easily work in research teams, thus the exercise is amenable to cooperative-learning techniques that we employ, such as the jigsaw (for example, see Aronson and others, 1978; Tewksbury, 1995). One benefit of this approach is that, when carried out correctly, it allows each student to take ownership of the project.

The lab we describe here is ideally suited for 15 to 30 students and is set up in the form of a jigsaw. Each student is responsible for completely understanding one component of the study (in our case field exercises 1, 2, or 3) which they will then teach to other students who have not performed that particular field activity. As instructors know quite well, one learns best by teaching, and we have designed this multi-faceted exercise so that each student is gently forced to teach the other students at least one aspect of the lab. Cooperative-learning approaches, such as this one, encourage critical thinking, develop problem-solving skills and long-term retention, and stimulate scientific curiosity (Johnson and others, 1991; Davidson and Worsham, 1992; Bruffee, 1993; Shea, 1995; Slavin, 1995). The laboratory exercise described below is divided into three parts. Principles of engineering, hydrology, and mathematics are used to characterize an irregularly shaped object (a river channel) and to determine the volume of water flowing through a cross section of the channel using spreadsheets. A portable chemistry set is used to evaluate the water quality of the river. Materials composing the stream bottom are examined for macroinvertebrates (mainly crustaceans and insect larvae) which are important components...
of the aquatic food chain and serve as biological indicators of water quality.

After each team of students has completed its field task (step 1 of the jigsaw method), the data are compiled and distributed to all students. During the next class period, each field team presents its results to the class; then one student from each field team is grouped with one member from each of the other field teams (step two of the jigsaw). These new groups work in class to analyze all of the data as described below. The final assignment, step three of the jigsaw, is for each group to meet outside of class to write an integrated summary report of the three field exercises and evaluate the water quality of the stream. It is during these final two exercises that each student becomes the teacher and explains his or her portion of the field exercise to the other students in the group. This final step is important for two reasons. First, it forces the student to take responsibility and serve in an advisory role for his newly acquired area of expertise. Second, and more importantly, the team-effort exercise develops talents that are becoming increasingly important in corporate America.

The hydrologic cycle is fundamental to many scientific disciplines (geology, Earth system science, environmental science, and so on). This exercise is a flexible one that can be modified (additional projects added, removed, and so forth) depending on the time available or the particular circumstances of a given campus. Our focus is on aquatic chemistry and ecology, but the exercise could be re-designed to emphasize fluvial processes or perhaps a comparative study of several water bodies. If a campus is located near a stream with a USGS gauge, then a very interesting semester-long monitoring project could be designed.

In the Field: Project Design and Data Collection

The exercise begins at the stream where a five- to ten-minute explanation of the lab exercise is given. This introduction is brief and does not include numerous details (as the goal is student-centered learning). Our approach is designed to outline a general method for scientific learning: set goals, make observations, collect data, interpret data, and draw conclusions. One question that we use to guide the students through the scientific method is, “Is the water of acceptable quality?” The students are divided into three field teams, allowing each student to select the team of most interest to him or her (water chemistry, macroinvertebrates, or stream flow). A detailed description of each exercise follows.

Team 1 Assignment: Characterization of the Stream Channel and Determination of Stream Flow

Objectives:
- learn field techniques for characterization of stream channels,
- determine the cross-sectional area of an irregularly shaped phenomenon (the stream channel) and introduce principles of calculating, specifically integration and limits, and
- learn to use spreadsheets and unit conversions.

Suggested Equipment:
- water-current meter (optional),
- tennis ball (for water-velocity measurements),
- ten-foot section of rope (for water-velocity measurements),
- rope marked at 0.5- or 1-foot intervals (depending on the size of the stream) and long enough to reach across the stream, alternatively a long measuring tape,
- stop watch,
- yardstick (for water-depth measurements), and
- laboratory notebook and ballpoint pens.

Perhaps the most time-consuming activity of this lab exercise, with respect to instructor preparation, is selection of a stream that will accommodate stream-flow measurements. The stream must have a relatively straight section that is safe enough to wade yet has sufficient water flow to allow accurate measurements. The first assignment for Team 1 is to figure out how to measure stream discharge (Wahl and others, 1995). Students invariably decide to measure water velocity and the channel cross section, but often need guidance in determining a suitable measurement interval. Once a method is devised, each student is assigned a task and the equipment is given out. The cross section of the stream is acquired by taking water-depth measurements at 0.5- to 5-foot intervals, depending on the size of the stream. Water velocity is measured by determining the time required for a tennis ball to travel 10 feet. Ideally this is measured between each depth point. This allows a water velocity for each section to be estimated (refer to Table 1). At this point students check their work, note any errors in their procedure, and improve on their method, sometimes even repeating the entire procedure. Student observations include (1) that ropes stretch and some error is introduced, (2) that stream currents do not flow in straight lines and some interpretation of the data is required, and (3) the path of the tennis ball (and thus the accuracy of the velocity measurement) is affected by where students stand in the stream. This exercise allows the student to observe, first-hand, that there is always some error associated with the collection of data and that scientists must consider the accuracy of their data when evaluating a data set. If time permits, an exercise in precision can be conducted by repeating the process either at the same location or at another point in the stream and comparing the discharge data from the two sites.

We are sometimes asked what happens if the students design an experiment that we know will fail. Our approach is to guide the students to a successful solution – or at least one that will produce valuable results. This means that we do let them fail, if that failure is a learning experience. Alternatively, we often run simultaneous experiments using different techniques. For example, we commonly employ two methods to measure water velocity. We bring a rotary current meter and have students compare results from the “low-tech” tennis-ball method and the “hi-tech” current-meter method of velocity measurement. Because we are working at the beginning of the fall semester, the current meter, which is not designed for low-flow
Table 1. Excel data sheet for stream flow analysis.

Even though it is tempting to tell the students where to go and what to do, we prefer to have the students design the procedure themselves, asking, “Where should water samples be taken?” “How should they be collected?” “How many measurements should be made?” This increased input by the students is the basis (and reward) of the guided-inquiry method. Usually a stream is selected that can be easily waded (one to two feet in depth) but has sufficient width and water flow to accommodate all team activities. Streams may have riffle areas where water velocity is high as well as nearly stagnant areas with low velocity; thus, varying chemical properties may result. In addition to the obvious riffle-versus-pool locations for sample collection, students may also wish to explore the effects of depth on water chemistry. Students usually select two to four sites of varying characteristics for sample collection. The results obtained for the different chemical parameters usually vary among sample sites, which raises an interesting question by the students, “Which of the results more accurately reflect the water quality of the stream?” This question opens up an opportunity to discuss aspects of precision, accuracy, and statistics, and why different areas of the stream produce different results.

A number of chemical measurements can be made in the field; the extent of the exercise is usually limited by time. We suggest measuring pH, temperature, hardness, dissolved oxygen, phosphate, nitrate, and possibly alkalinity. If more emphasis is to be placed on ecology, biochemical oxygen demand (BOD), fecal coliform, and turbidity measurement can also be included. A common question asked by students during each of these measurements is, “Why are we measuring this parameter?” and “How does the instrument work?” This often leads to a variety of interesting discussions. After taking a measurement, it is inevitable that someone will ask, “Is this measurement ‘good’?”, which serves as an excellent point of discussion when we process the data back in the classroom. During this discussion, the student has the opportunity to interact and compare data obtained by the macroinvertebrate team.

A variety of field equipment is commercially available, but perhaps the best all around kit for pH, conductivity, and wet chemical measurement is the portable lab available from Hach (Hach Company World Headquarters. P.O. Box 359, Loveland, CO 80539; 1-800-227-4224). The kit is sold in a modular manner and ranges from a hand-held pH meter (Hach Model EC10) to the complete system (Hach DREL2010 Water Quality Laboratory) containing titration equipment and a spectrophotometer. The latter system can be used to analyze for a “nearly complete” set of nutrients. A large number of hand-held dissolved oxygen meters and probes are available, most with built-in temperature sensors. Details on each of these chemical measurements can be found in Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1992).

Team 2 Assignment: Water Chemistry

Objectives:
- learn basic approaches for measuring water chemistry parameters,
- distinguish between accuracy and precision, and
- learn to use spreadsheets and unit conversions.

Suggested Equipment:
- portable laboratory kit with dissolved oxygen probe, spectrophotometer, conductivity meter, pH meter,
- sampling bottles,
- laboratory notebook and ballpoint pens.

Team 3 Assignment: Macroinvertebrate Sampling

Objectives:
- learn basic approaches for collecting macroinvertebrates and

• determine the diversity of a biological community.

Suggested Equipment:
• four sticks for staking off the sampling area and a fine mesh net or Surber macroinvertebrate sampler,
• dissecting microscope (optional),
• white buckets, white sorting trays, and forceps,
• macroinvertebrate key (referenced below), and
• laboratory notebook and ballpoint pens.

Although simple chemical measurements, such as those conducted by Team 2, may indicate that a stream has adequate water quality, toxic chemicals (for example, DDT, PCBs, Hg, and so forth) that cannot be easily measured may be present. For example, our watershed, the upper Susquehanna, has a significant problem with environmental mercury contamination (NYSDEC, 1996). One simple way to evaluate the overall quality of a stream is to determine the diversity of aquatic invertebrates, commonly referred to as macroinvertebrates. Macroinvertebrates can be found on most stream substrates such as rocks, sticks, leaf litter, and logs. As in the water-quality measurements, variation in stream flow resulting in alternating riffle and pool areas is likely to produce different biological communities in each of these areas. Thus, the first task for Team 3 is also to determine where to collect samples. An interesting question to pose is to ask students whether they think diversity will be greater in the riffle area or the pool area. Usually sampling is conducted in as many different areas as time permits, but it should be noted that considerable time is required to analyze the samples.

The best way to collect macroinvertebrates is with a Surber sampler (Forestry Suppliers, Jackson, MS, 1-800-752-8460), which consists of a metal frame that allows a one-square-foot (929 cm²) area to be sampled. Stream-bottom materials contained in this area are gently brushed to remove macroinvertebrates that are subsequently washed into a collection net positioned downstream. If a Surber sampler is not available, a one-square-foot area can be marked off with sticks and the macroinvertebrates collected in a net that is held immediately downstream of the sampling area. After collection, the macroinvertebrates are washed into a bucket for sorting and counting. At this point students usually ask “Why are we collecting only in a one-square-foot area.” This can serve as a springboard for later classroom discussions on (1) how much biomass is contained in a given section of the stream (based on the area sampled and the biomass in the square-foot area), (2) how do biological communities differ between the sampling sites, and (3) what is the nature of the food web.

One simple method for estimating the diversity of a stream is to calculate a Sequential Comparison Index (SCI) (Enger and Smith, 1995). An alternative method that uses the same data is the Biotic Index (Lehmkuhl, 1979) which is adapted from a method developed by Hilsenhoff (1977). Both of these indices are easy to use because it is not necessary to determine the species of the organism but only to recognize if it is morphologically different from the last organism examined.

These indices are, however, indicators of ecological diversity because each takes into account the species richness and the abundance of individuals of each species (evenness). This procedure can be completed using the following steps:

1) Set up trays for sorting the macroinvertebrates.
2) Remove individuals from the collection tray in a random manner. This can be accomplished by lining up the students in a row so that they cannot see what the person in front is doing. Allow the first student to remove the first organism that they see from the bucket and place it in a sorting tray. This starts a run (described below and in Table 1).
3) Give each organism of similar morphology a label, for example, “A, B, C,” and so on and place similar organisms in a single tray.
4) The next student in line removes the first organism that they see. If the selected organism is the same as the previously selected organism, it is counted in the same Run. If the organism is different, a new Run is started (refer to Table 1).
5) This procedure is followed until all of the organisms have been removed from the bucket.
6) Compile the information (the number of runs and the number of individuals in your sample). As time permits the field team may sample and analyze additional sites.

For example, five kinds of organisms, A, B, C, D, and E, were selected and the data are shown in Table 2. In Table 2, there were 6 runs and 15 individuals. (The first three organisms selected were of species D and the fourth was of species E which started a new run.) The SCI equals the number of runs divided by the number of individuals. In this case: 6/15 = 0.4. The closer the SCI number is to 1.0, the higher the species diversity of the stream. In a highly diverse system, a new type of organism would most likely be drawn each time, thus starting a new run with each student. After calculation of the SCI, it is useful to return to the concept of the food web and discuss the consequences of species reduction.

Instructors not trained in identifying insects may shy away from this exercise, but it is actually quite simple. The number of different organisms identified using this morphology-difference approach is typically less than ten, all of which are easily identified using

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Type of Organism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>DDD</td>
</tr>
<tr>
<td>Run 2</td>
<td>EEE</td>
</tr>
<tr>
<td>Run 3</td>
<td>A</td>
</tr>
<tr>
<td>Run 4</td>
<td>DD</td>
</tr>
<tr>
<td>Run 5</td>
<td>BB</td>
</tr>
<tr>
<td>Run 6</td>
<td>CCCCC</td>
</tr>
</tbody>
</table>

Table 2. Macroinvertebrate results from one sampling station.
macrionvertebrate keys that are readily available from local water-quality and wildlife organizations (State Department of Environmental Conservation or Water Quality). Common macroinvertebrates include several easily distinguishable groups, such as crayfish, water pennies, caddisflies, mayflies, stoneflies, planaria, nematodes, snails, damselflies, and dobsonflies. If keys are not available from local organizations, one can consult a reference text such as Ward and Wipple (1959) or Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1992). Keys usually contain information on chemical tolerances such as dissolved-oxygen requirements and pH limitations, as well as some information concerning the quality of the water in which the species is commonly found. Thus, results from Teams 2 and 3 can be compared during classroom discussions.

In-Class Activities: Data Synthesis
After returning from the field, the students are reassigned to “report groups” consisting of one student from each field team. The goal here is peer instruction. This is also an appropriate time for instructors to help students synthesize their data and understand the significance of their results. We find that discussion of the students’ work after they return from the field has more impact than extensive pre-lab lecturing. Additionally, each activity in this jigsaw affords an excellent opportunity for students to learn to use spreadsheets. The complexity of the spreadsheets increases from Teams 2 and 3 to Team 1.

Students are required to construct summary tables and graphs of all data. The stream-chemistry data from Team 2 provide an excellent opportunity to illustrate how to implement simple equations in spreadsheet cells. Exercises that we use include conversion of temperature measurements from Fahrenheit to Celsius and conversion of mg/L to moles/L (for use in chemistry lectures). Team 2 is also asked to evaluate its stream data in light of acceptable stream or emission limits for the chemical parameters tested in the field. This part of the discussion can be extended to include other chemical parameters. Acceptable limits vary from state to state, but can be obtained from the local State Department of Environmental Conservation or Water Quality. An alternative would be to use the data published in Leeden and others (1990).

Data from Team 3 can be compiled to create a frequency plot which shows the occurrence of each species (Figure 2). At this point, some excellent questions can be asked: “Were there any differences among the sampling sites?” “What variation might have been observed in different types of sampling sites?” “Were there any sections of the stream that were not sampled (for example, deep regions of the stream)?” “Was the variation between the sampling sites greater or less than between samples from the same site?” Additional discussions could involve comparisons of the water chemistry to the observed species. For example, “Do the observed chemical concentrations effectively eliminate any types of organisms?”

Results from Team 1 allow an extensive classroom exercise using spreadsheets where students can turn their field data into physical and mathematical models. Each student is given a compiled data set, and we guide them through an exercise in building a spreadsheet and associated graphs. For most first-year students this is their first exposure to spreadsheets, especially tasks such as embedding equations in cells, and we carefully walk the student through a step-by-step procedure. Results from an example cross-section of a stream are given in Table 2. The data from Table 1 are plotted in Figure 3. Figures 3a and 3b show an approximation of the stream channel (data not available to students unless water-depth measurements are taken every 0.1 feet. This line is used here for illustrative purposes only). Figure 3b is an inverted version of the stream-channel data. Note that the scale between the x- and y-axis is different. The larger solid squares in these figures indicate where depth measurements were made, and the arrows show where water-velocity measurements were made (midway between the depth-measurements points). The next task for the students is to use their data to calculate the cross-sectional area of the stream. The students then calculate stream discharge (in ft³/s): the product of the cross-sectional area (in ft²) and the water velocity (in ft/s) Note that in the field we used feet and square feet, units that are more familiar to students. Additionally, USGS stream-gauge data are still reported in cfs. These measurements can be converted to metric units in the spreadsheet if desired.

The first step in determining the cross-sectional area is to plot an inverted cross-sectional area (Figure 3b). Students note that if the plot is divided into simple sections (triangles and trapezoids), they can estimate the area of each of these shapes. The area of each shape is calculated by inserting the appropriate equation in the spreadsheet cells. Subsequently, if the individual areas are summed in the spreadsheet, the total area of the cross section can be estimated. This
provide sufficient details to allow anyone with a similar educational level to reproduce the results exactly. We have also found that strict guidelines should be given on what to include in the report (all data in proper units, procedures, plots, and discussion of the results). This is the most difficult aspect of the labs for the students. While group efforts work well during "hands-on" activities at the stream, tensions may develop as the students divide the task of preparing a report. To avoid this problem and promote a true group effort in writing the report, an instructor should meet with the students (outside of class) at least once during the report-writing phase of the lab exercise. Emphasis should be placed on preparing an integrated report, not one where each student independently writes a section of the report.

**Difficulties**

This lab exercise works best when there is a high teacher-to-student ratio. We currently have the luxury of having three instructors and one TA for 28 students. While our teacher-to-student ratio will be reduced in the future, any interdisciplinary effort presents challenges for college and university administrators who are committed to offering interdisciplinary programs, but who are also held to traditional teacher workloads. Creative use of faculty, graduate, and undergraduate teaching assistants is very helpful.

Another difficulty associated with any guided-inquiry field project is that such projects are always more time consuming than in-class exercises, but the benefits of field exercises in our opinion far outweigh the time investment. We have found that the extra effort is rewarded by a sense of ownership by the students and an increase in scientific curiosity. Students are empowered when they realize that they are actually engaged in the process of scientific inquiry. It is too early to judge the long-term impact of this particular laboratory, but we hope that this and similar exercises encourage students to become lifelong learners and improve the scientific literacy of non-science majors.

**Conclusions**

While there has been much discussion of science illiteracy, a recent National Science Board report quantifies the problem. On a ten-point science-literacy quiz administered by the Chicago Academy of Sciences, the mean score for American adults was 5.2 correct answers (NSB, 1996). College graduates in the group fared only slightly better with a mean grade of 6.4.

With respect to understanding the nature of scientific inquiry, only 6% of college graduates understand science as the development and testing of theory, 44% understand the concept of experimental study and 37% (of college graduates) have little understanding of scientific inquiry at all (for the general public this figure is 64%). In this last group, the National Science Board notes a "wariness that appears to flow from recognizing the enormous power of science and technology and the individual's almost total lack of understanding of it...the work of scientists and the process of scientific inquiry are black boxes, at best."
We firmly believe that students learn science best and learn to appreciate science if they are actively involved in the process of inquiry. Open-ended field exercises, such as the one described here, are excellent ways of stimulating student interest since the students actually design their experimental strategy, collect data, analyze it, and learn from their experiences. Approaches such as this, in fact, entire courses taught in this manner, will be required to attract talented students into science classrooms. This is not to say that the “drier” topics of science can no longer be taught; it simply means that we must design guided-inquiry exercises for their instruction. We have focused our curriculum-development efforts on first-year non-science majors because we believe that it is most important for students who are not science majors to understand the process of science and because in many instances an introductory-level course (or two) will be the only classes in science these students ever take.

Acknowledgments
This work was supported in part by funding from the National Science Foundation, grant #DUE-96553090.

References

About the Authors
Frank Duniway, Meredith Newman, Ronald Brzenk, Alexandra Moore, and Mary Jo Alfano all teach science at Hartwick College. Their experience in the classroom ranges from that of Brzenk who is a 30-year veteran to Mary Jo Alfano who graduated in 1997 with a double major in chemistry and geology. The authors are part of a group of nine faculty who have designed a new integrated, interdisciplinary science curriculum for first-year students.