# Integration of Field Observations with Laboratory Modeling for Understanding Hydrologic Processes in an Undergraduate Earth-Science Course

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## ABSTRACT

Understanding how water is transported and stored in the subsurface is a difficult concept for introductory earth-science students. We have developed a hydrology minicourse that integrates field and laboratory experiences to help undergraduate students gain a better understanding of ground-water flow in aquifers. The centerpiece of the minicourse is an investigative field trip that permits analysis of a local aquifer that provides drinking water for the university community. Students collect qualitative and quantitative field data on grain size, thickness, and geometry of different stratigraphic horizons within the aquifer and then construct a small-scale laboratory model of the aquifer using boundary conditions determined from the field investigation. The aquifer model allows students to test hypotheses of ground-water flow by conducting a series of modeling experiments. The experiments test questions such as: "What is the influence of porosity and permeability on ground-water flow?" and "What is the effect of regional dip on ground-water flow?" Analysis of pre- and post-minicourse examinations demonstrates that students are able to better communicate fundamental hydrologic concepts after completing the minicourse.

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

## INTRODUCTION

Recent science-education reform efforts have encouraged the development of "hands-on" laboratory and field activities to improve undergraduate science courses (for example, NSF, 1996; Boyer Commission, 1998). In addition, many science-education reform recommendations call for "active" learning styles that foster critical thinking and problem solving rather than "passive" learning (AAAS, 1993; NRC, 1997). This article outlines an innovative teaching approach that we developed at Purdue University to help students actively investigate ground-water flow in aquifers using "hands-on" field and laboratory activities. Various concepts in hydrology, particularly ground-water flow, have historically been difficult topics for undergraduate students to learn in a meaningful way. This difficulty can be attributed, in part, to the inherent complexity of the topic and the fact that hydrology is commonly not discussed in high-school science courses so students have no useful background preparation. As part of an introductory earth-science course for pre-service teachers, we have the students (1) participate in an investigative field trip that provides analysis of aquifers, watersheds, and watertables, (2) construct a small-scale laboratory model of an aquifer using boundary conditions determined during the field investigation, and (3) test working hypotheses of ground-water flow by conducting a series of laboratory experiments using the model. The field trip allows students to make direct observations, collect scientific data, experience the scale and complexity of geologic problems, think critically, and formulate field-based hypotheses. The laboratory modeling helps students discover fundamental hydrologic concepts that are difficult to observe in the field, such as regional fluid flow through an aquifer. This study presents results from an introductory geoscience course for pre-service teachers, but the hydrologic concepts and teaching approaches can be applied in a variety of introductory courses.

The approach used in the course is unique in that observations that students make in the field form the boundary conditions of their model and laboratory experiments. Numerous studies have demonstrated the educational effectiveness of field experiences (for example, Novak, 1976; Mason, 1980; Orion, 1989; Orion, 1993), but few studies have reported on the influence of integrating laboratory and field experiences (for example, deWet, 1994). In this article, we discuss how we attempt to have students connect field-trip observations with laboratory modeling in an introductory undergraduate course for pre-service teachers. In traditional classrooms, students are often provided with predetermined boundary conditions as part of a modeling exercise. Our approach allows the students to determine the appropriate boundary conditions themselves, through observing natural phenomena in the field. This method allows pre-service teachers to understand science as a process and, subsequently, to teach scientific concepts in a meaningful way.

The team that created and assessed the hydrology minicourse at Purdue University worked as part of the Collaborative Action Based Research (CABR) Pilot Program sponsored by the National Science Foundation. Individuals working on the CABR project made use of action research (Hamilton, 1995; Keating and others, 1998) to promote change in the instruction of undergraduate science courses, especially those taken by pre-service teachers, and to enhance students' understanding of scientific concepts. The action research team for this study included faculty members in geoscience and geoscience education, an elementary-school teacher, a graduate teaching assistant in education, a graduate teaching assistant in geoscience, and two undergraduate students in education who had completed the course. This diverse team structure was designed to provide multiple perspectives for instruction of the course material as well as interpretation of research data collected to evaluate the educational effectiveness of the minicourse. We also discuss a variety of evaluation techniques that were used to determine how this integrated approach affected students' conceptual understanding of hydrologic processes.

Our teaching methods include: (1) having students make observations of natural phenomena, (2) prompting students to use their observations to develop scientific hypotheses, and (3) providing students an opportunity to construct a laboratory model to test their hypotheses. We emphasize students actively working as scientists rather than having them read about or listen to lectures about what scientists have already discovered. Students emulate scientists by making observations, developing hypotheses, and designing experiments to test their hypotheses. During the minicourse, the role of the instructor is to assist student exploration and discovery by providing opportunities for them to make scientific observations. Our approach also tries to change the expectations of elementary-education majors, many of whom expect scientists to simply provide them with the "right" answers. We hope that the future teachers will be able to teach science as a process by incorporating similar teaching approaches in their science courses (Manner, 1998). Finally, in an effort to improve student collaborative skills, they are required to work in small teams in each phase of the minicourse.

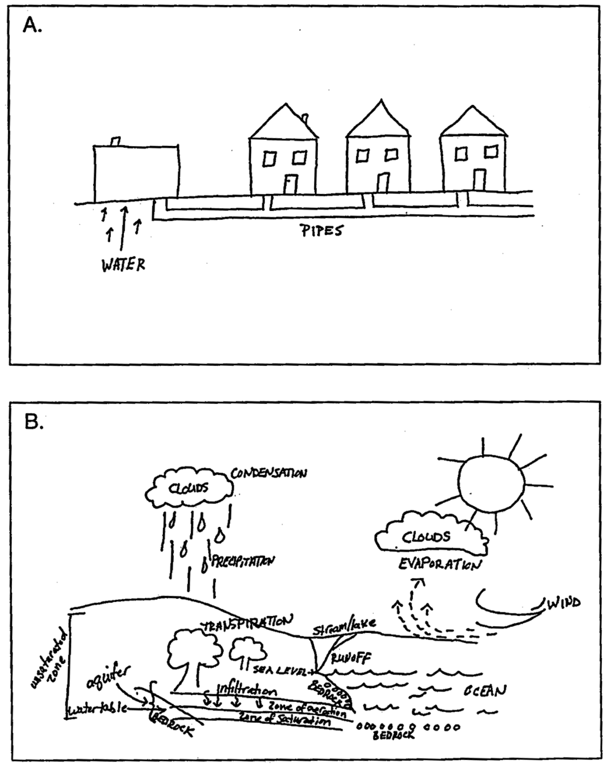


**Figure 1. A) Actual pre-minicourse sketch by a student who was asked to explain the following questions: Where does ground water originate and how does it travel in the subsurface? B) Post-minicourse sketch by a student who was asked to explain the following questions: Where does ground water originate and how does ground water travel in the subsurface? The student was also asked to explain the entire hydrologic cycle, so the diagram includes more components of hydrology than the sketch in Figure 1A. Note the apparent improved understanding of the origin of ground water, the role of aquifers, and the impact of regional gradient on groundwater transportation.**

## FIELD TRIP

### Procedure

The hydrology minicourse consists of four interrelated steps that are completed in six class periods: a preparatory unit, an investigative field trip, laboratory modeling exercises, and a classroom synthesis. Before the preparatory unit, students are interviewed individually by course instructors to determine their prior knowledge of hydrologic concepts. In addition to answering a series of questions about hydrology, students are asked to draw a sketch of how ground water migrates in the subsurface (Figure 1A). In the preparatory unit, students complete instructor-provided worksheets that introduce the fundamental concepts to be covered during the minicourse. To help students gain this basic knowledge, instructors also provide extensive resources, including journal articles, web-site addresses, and handouts that can be used throughout the minicourse. Students participate in the hydrology field trip as soon as they complete the preparatory unit. The main goals of the field trip are to have students: (1) actively collect, compile, and interpret geologic field data, (2) effectively experience the scale, complexity, and three-dimensional spatial characteristics of a watershed and an aquifer, (3) realize the limitations of real scientific data sets, (4) effectively communicate their observations and interpretations orally, (5) formulate and test working hypotheses in the field, and (6) propose additional laboratory investigations to evaluate hypotheses developed in the field.

The 22-km field-trip route is completed during the normal allotted classroom time (110 minutes). Instead of taking the entire class to the field at once, instructors conduct the same field trip multiple times with small groups of students. With two instructors and only six to eight students in the field at once, student-instructor interaction is frequent and group discussions involve each student. Although students are prompted through oral questioning by the instructors, observation- and inquiry-based learning is emphasized throughout the field trip. The field trip includes four stops that are outlined below.

### Geologic Setting

Purdue University is located in west-central Indiana, a region that underwent multiple Pleistocene glaciations, which deposited gravel, sand, and mud unconformably above Paleozoic strata (Figure 2). Pleistocene sediments were deposited by ice-contact processes and by eolian, fluvial, and lacustrine depositional systems located adjacent to ice margins. Repeated glacial advance and retreat resulted in depositional units that are laterally and vertically heterogeneous with abrupt changes in grain size, sorting, and bedding thickness. The unconsolidated Pleistocene deposits are the primary hosts for migration and storage of ground water in the study area. Subsurface aquifers within the Pleistocene glacial sediments supply most of the drinking-water that is used at Purdue University (Figure 2).

## Field Sites

**Stop 1 –** *Purdue University water wells and chlorination facility.*
*Purpose*: Introduce students to basic hydrologic concepts including ground water, aquifers, and the source of local drinking water supplies.

*Procedure*: After hearing an overview of the main learning objectives and itinerary of the field trip, the students are taken to a campus water-well field located less than one mile from the classroom (Stop 1 on Figure 2). Inside unmarked brick buildings at this locality, there are water wells and chlorination facilities that supply most of the drinking water for the university community. Upon arrival at the well field, students are asked the following question: "Where do you think the water you drink on campus comes from?" Students are encouraged to discuss possible answers to this question in small groups. The most common answers from students are that water is taken directly from the Wabash River (Figure 2), from Lake Michigan (located 90 miles north of Purdue University), or from pipes originating from unknown sources. On the basis of this brief exercise, it is evident that prior to the field trip, the students are unaware that local drinking water is derived from shallow aquifers located directly beneath the campus. Instructors promote further discussion by demonstrating that the brick buildings contain water wells and chlorination facilities. This knowledge allows students to consider the following questions: "Where is the water being stored in the subsurface?" and "What are the physical characteristics of the subsurface (aquifer)?" Stop 2 is designed to help students answer these questions firsthand.

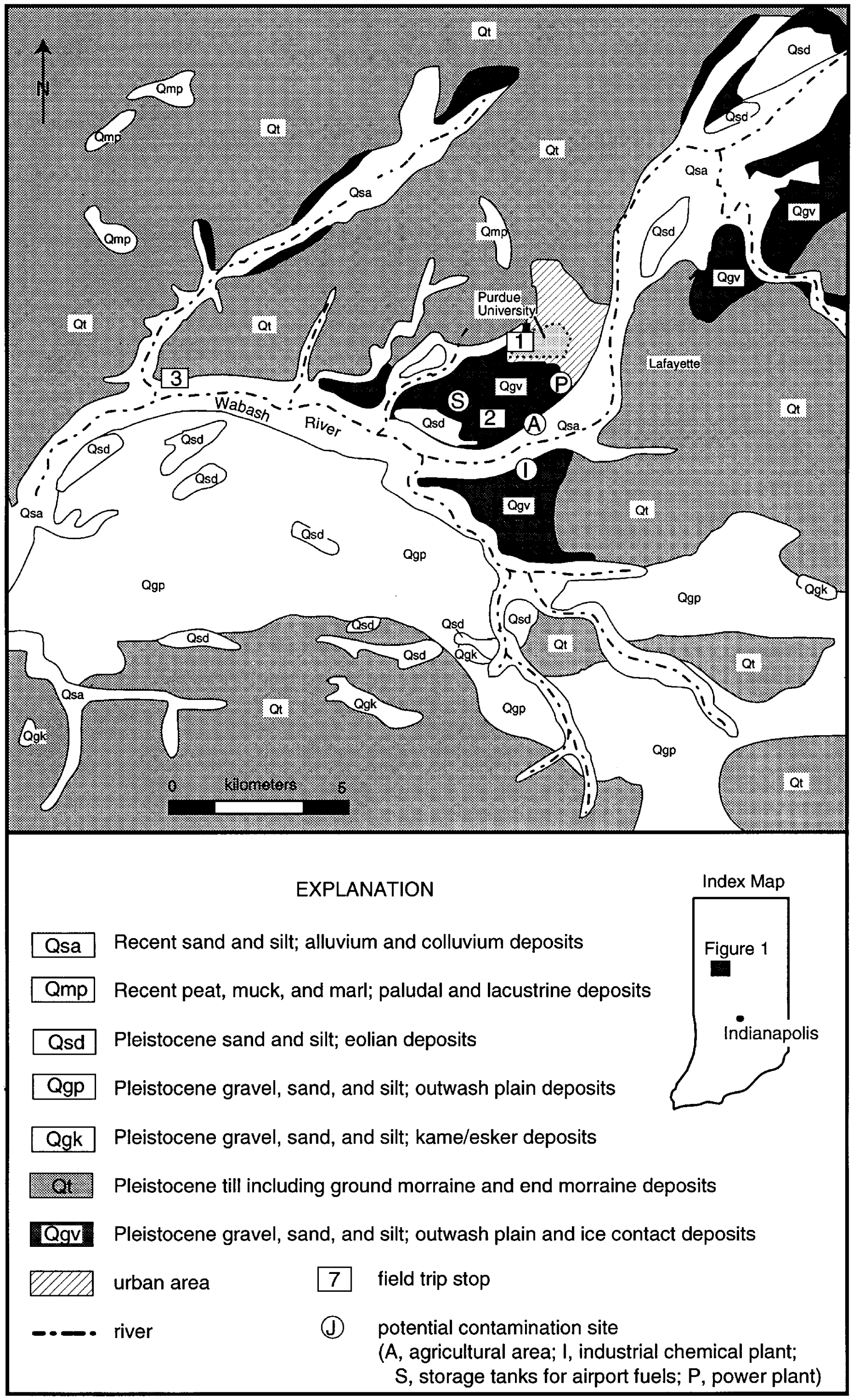


**Figure 2. Generalized geologic map of part of the 1° x 2° Danville quadrangle, Indiana. Map location shown on index map of Indiana. Note that the study area is dominated by Pleistocene proglacial and ice-contact deposits and recent sediments. Geology adapted from Wayne and others (1966).**

**Stop 2 –** *Pleistocene aquifer.*
*Purpose:* Have students make direct observations concerning the physical characteristics of an aquifer and develop working hypotheses as to the physical controls on groundwater migration within an aquifer.

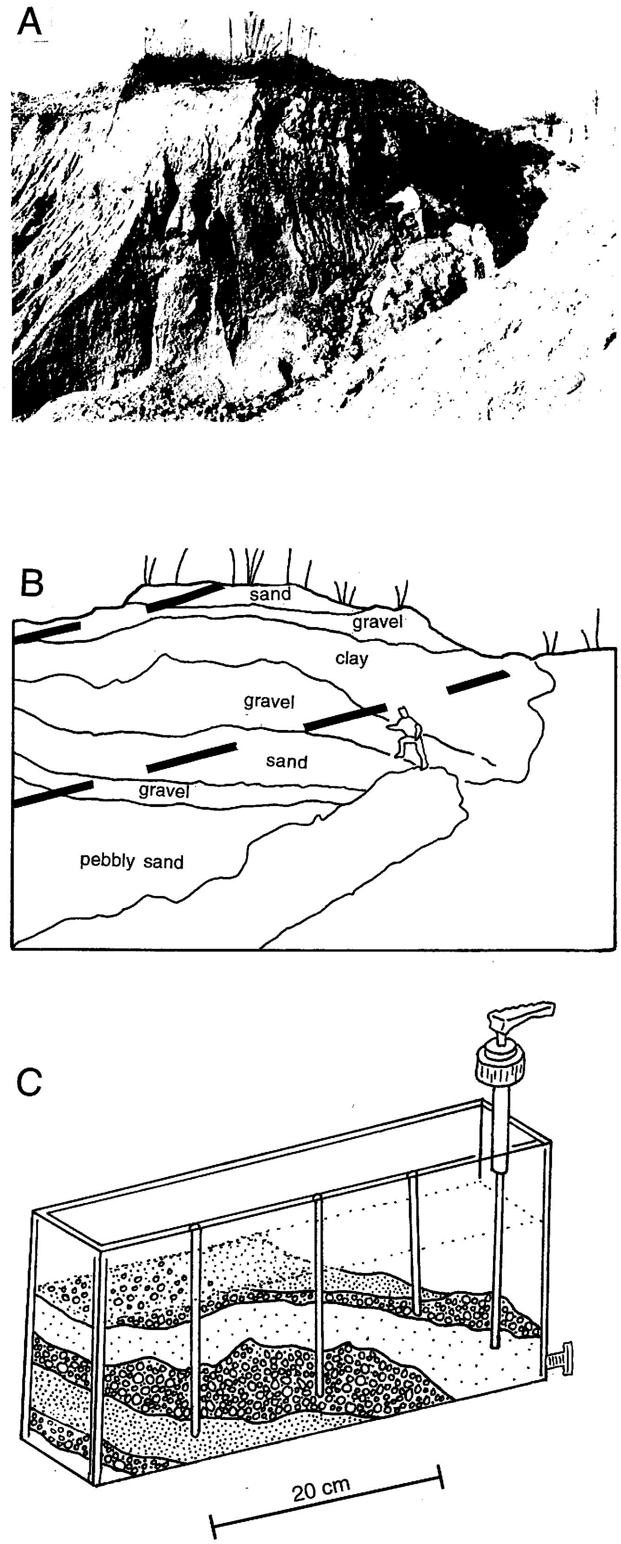


**Figure 3 (right). A. Photograph of a typical outcrop face examined by students at Stop 2. Note the heterogeneity in the outcrop that is a product of variations in grain size and bed thickness. Person (right center) for scale. B. Line drawing interpretation of the outcrop face shown in Figure 3A. Dashed lines mark the part of the outcrop modeled in the laboratory (Figure 3C). C. Sketch of a hydrology model constructed by students for laboratory experiments. Students arrange grain sizes in the model according to their observations of an outcrop face examined in the field (aquifer at Stop 2). For example, in the model shown here, gravel, pebbly sand, sand, and clay are arranged from part of the outcrop face shown in Figures 3A, B. The part of the outcrop that is modeled is outlined by the heavy black dashed lines in Figure 3B. Water wells (four vertical cylinders) are installed at variable depths in the modeled aquifer. A moveable pump (shown in well on upper right) can be installed in the water wells to perform pump tests. A small plug (lower right) is used to drain the model in order to study ground-water-transport rates.**

*Procedure:* Stop 2 is a sand and gravel quarry in which students inspect Pleistocene deposits that form the uppermost part of the aquifer that supplies drinking water to Purdue University (Stop 1 on Figure 2). The quarry is located at the southern edge of campus, four km from Stop 1 (Figure 2). The primary objective at the quarry is to have students make detailed observations concerning the lateral and vertical arrangement of unconsolidated sediment comprising the aquifer (Figures 3A, B). After dividing into small groups, students examine different sections of the well exposed quarry walls and make observations concerning the lateral and vertical variations in grain size (gravel, sand, and mud), sedimentary structures (cross-stratification, clast imbrication, and channels), and presence or absence of ground water. Students are provided with tape measures, graph paper, trenching materials, and hardhats and are encouraged to measure stratigraphic sections, construct detailed field sketches, make qualitative descriptions, and collect quantitative data (for example, percent gravel, sand, and shale). The excellent exposures and pronounced variations in grain size, bed thickness, bed geometry, and sedimentary structures permit first-order observations regardless of students' prior knowledge of geology (Figures 3A, B). The students are encouraged to dig into the sediment to determine whether fluids are actually present within the aquifer. Most students readily identify interbedded clay horizons that act as confining layers and partition sand- and gravel-dominated zones of high porosity and permeability. Water is often concentrated along the interface between clay horizons and overlying sand and gravel.

After the field data have been collected, student-led discussions allow them to share what they have discovered by comparing and contrasting the physical characteristics of different parts of the quarry. They are then encouraged to develop working hypotheses on how ground water would be transported through different parts of the aquifer. As part of a group discussion, they consider questions such as: "Is the aquifer lithologically homogeneous or heterogeneous?"; "Is ground water more prevalent in certain parts of the aquifer than others?"; "Why?" "What lithologies appear to transport and/or contain the most ground water?"; "Why?"; "Where in the quarry would a water well be installed to maximize intake of shallow ground water?"

After completion of the sedimentological analyses, the gravels layers are reexamined to determine the clast composition. The goal of this exercise is to have students collect and interpret quantitative data sets that encourage consideration of the role that variations in gravel-clast types might have on ground-water quality. Each group of students documents the gravel-clast composition of a representative portion of an outcrop face by identifying and recording each clast located within a delineated rectangle. At this point in the course, students have had experience identifying rocks and minerals using hand lenses, hydrochloric acid, and streak plates. Students will later compile and interpret the compositional data during the laboratory portion of the minicourse.

**Stop 3 -** *Regional traverse.*
*Purpose*: Expose students to hydrologic concepts concerning regional transportation and storage of ground water.

*Procedure*: After discovering that local water supplies are drawn from subsurface aquifers, the students consider the migration pathways of water from the surface to the subsurface as well as potential sources of ground-water contamination along the pathways. A traverse is taken through a local watershed, progressing downdip through the regional gradient, eventually ending at the Wabash River, the local water table (Stop 3 on Figure 2). As the traverse progresses towards the river, students are asked to identify sites where water is actively migrating or being stored at the surface (for example, streams, lakes, and marshes) and to hypothesize how it might be migrating in the subsurface in response to the regional gradient. The students also identify and discuss potential sources of ground-water contamination observed during the traverse, which include an industrial chemical plant, a power plant, agricultural lands, and gasoline storage tanks (I, P, A, and S on Figure 2).

As a related side project, at the end of the traverse, students study modern fluvial depositional systems near the confluence of a small stream with the Wabash River (Stop 3 on Figure 2). Students compare the arrangement of grain sizes and sedimentary structures in the modern fluvial depositional environment with those of the Pleistocene proglacial outwash deposits that they described at the aquifer (Stop 2). This exercise introduces the general concept that study of modern depositional systems may provide insight into ancient depositional processes and environments.

## LABORATORY EXERCISES

Upon returning from the field trip, the students integrate their field observations with laboratory exercises by constructing a small-scale model of the aquifer that they observed in the field (Figure 3C). They are provided with a hydrologic-model kit (Figure 3C) and pre-sieved pebbles, coarse-grained sand, medium-grained sand, fine-grained sand, silt, and clay. After assembling the kit, students use their field sketches, measured stratigraphic sections, descriptions, and quantitative grain-size data to arrange sediment in the laboratory model in a manner similar to the outcrop that they studied in detail at the aquifer (Figure 3B, C).

The students then conduct a series of experiments that verify or refute their field-based hypotheses concerning the physical controls on ground-water transportation (for example, ground water migrates more rapidly through gravel than sand; clay interbeds act as vertical flow barriers in an aquifer). Students conduct experiments to evaluate the role of porosity and permeability on infiltration rates, examine aquifer recharge and discharge, and study the influence that regional dip has on ground-water transportation. The model has monitoring wells and an outlet that can be used to test flow rates through different lithologies and clear walls that permit visual inspection of fluid-migration pathways (fluids are mixed with a bright-colored dye). Detailed descriptions and step-by-step instructions of the laboratory experiments that were used with the hydrology model can be obtained from the Denver Earth Science Project (http://www.mines.edu/Outreach/Cont_Ed/esrc.shtml/pgwm). The students then compare the results of their simulations with those of other groups who observed and modeled different parts of the aquifer in the field. By comparing results, they are able to evaluate how lithology, bed thickness, and bed geometry may control the way fluids are transported and stored in an aquifer.

A second laboratory exercise involves compilation and interpretation of the gravel-clast composition data that the students collected from the aquifer during the field trip. The gravels include metamorphic and igneous clasts that were most likely derived from Precambrian source terranes exposed in Canada, northern Minnesota, and Wisconsin, in addition to clastic and carbonate rocks derived from local Paleozoic sources in Indiana and Illinois. By comparing data sets obtained from different lateral and vertical positions in the quarry, students document compositional variations in gravels within the aquifer. In considering the possible implications of ground water interacting with different rock types, students address the following questions: "What potential water-quality problems could result from aquifers comprised mainly of carbonate gravel clasts," "from igneous clasts rich in heavy minerals," "from poorly consolidated shale clasts"; "What gravels in the quarry might yield the highest quality ground water on the basis of its gravel-clast composition," "Why." The students discuss hypotheses relevant to these questions among themselves and are encouraged to seek additional information so they can understand these important concepts. After completion of the field trip and laboratory experiments, the students synthesize fundamental concepts by completing a series of worksheets and a final examination.

## ASSESSMENT, REVISION, AND FUTURE DIRECTIONS

To test the educational effectiveness of integrating field observations with laboratory modeling, we investigated the following question: "Are students able to understand ground-water migration in an aquifer if they participate in a minicourse that integrates field-trip and laboratory experiences?" Our investigation of this question included two main assessment strategies: (1) pre- and post-testing through oral and written questions answered during formal interviews and (2) post-testing through essay, short answer, and multiple-choice questions answered as part of a final written examination. Our analysis is based on assessment of 80 students from four classes taught in four consecutive semesters. In pre- and post-interviews, the students were asked questions concerning fundamental hydrologic concepts relevant to the minicourse and asked to demonstrate connectedness among these concepts (Table 1; Figure 1B). The key point from our analysis is that, after completing the course, they were more capable of effectively describing, both orally and with sketches, the connectedness between natural phenomena observed in nature (for example, aquifers, watersheds, lithologies, ground water) and abstract concepts that are difficult to observe directly but can be modeled in the laboratory (for example, regional fluid flow). In contrast to sketches drawn in pre-minicourse interviews, post-minicourse sketches illustrate aquifer heterogeneity, fluids migrating faster through more porous and permeable parts of an aquifer, and fluids migrating downdip in response to a regional gradient (Figure 1B). Analysis of students' written responses to final-exam questions suggests that they gained more knowledge from field and laboratory experiences than from worksheets or classroom lectures. The most frequently missed exam questions concerned concepts not experienced during the field trip or laboratory components of the course. Importantly, analyses of essay responses indicate that students understood what they were modeling in the laboratory and why the modeling was necessary to test their working hypotheses. Although our research methodology did not include rigorous statistical analyses, randomized field trials, or control groups that would better substantiate the effectiveness of our approach (Shea, 1999), we contend that the pre- and post-testing results clearly demonstrate that student learning occurred. Recent research indicates that despite the intensity or effectiveness of the teaching experience, learning is influenced by the amount of time students are exposed to the studied material (Gabel, 1994). To address the issue of the length of time of student involvement with this topic, the two-week minicourse has been infused into a five-week minicourse that builds upon the role of the field trip and its modeling via laboratory experiences. Future research will be conducted to assess the impact of a longer minicourse on student learning of the geosciences.

We also documented student opinions of the techniques used and monitored student attitudes towards learning during the minicourse (Table 1). Analysis of student e-mail journals, student-opinion surveys, and course evaluations reveals positive responses to the teaching techniques used in the hydrology minicourse. In response to student suggestions for improving the minicourse, we have increased the amount of time allowed to make observations in the field, reduced the complexity of some of the laboratory experiments, and added "wrap-up" sessions to both the laboratory and field experiments. Future minicourse modifications that we are planning include: (1) providing subsurface data (for example, well logs) from additional field sites in the study area on a web site so that students can make more regional observations, interpretations, and predictions, (2) retooling the laboratory component of the minicourse to include collection and analysis of more quantitative data sets to stress the interrelatedness of science and mathematics (for example, in addition to calculating porosity, permeability, and flow rates, students will determine the probability that one part of an aquifer will recharge faster than another), and (3) viewing of a videotape during the preparatory unit that shows each component of the minicourse from previous semesters to help students

| Technique | Results |
|---|---|
| ***Assessment by instructors*** | |
| Pre- and post-minicourse examination (formal interviews with sketches) | After the minicourse, students were able to better communicate orally and with sketches the origin of ground water, how ground water migrates in the subsurface, and how the physical characteristics of the subsurface influence transportation and storage of ground water. Post-minicourse sketches provide direct evidence that students made fundamental connections between field observations and laboratory modeling exercises. |
| Post-minicourse final examination (written multiple-choice, short-answer, and essay questions) | The most frequently missed exam questions concerned topics that were not covered in the field or laboratory. Answers to essay questions strongly suggest that most students understood what they were modeling in the laboratory and why the modeling was necessary. |
| ***Assessment by students*** | |
| Student survey | A large majority of students stated that they learned the most by making field observations in association with "real" geoscientists and/or participating in group discussions while in the field. A smaller proportion indicated that they learned the most from the laboratory modeling experiences. |
| Course evaluation | Analysis of course evaluations suggest that students were interested in learning hydrology because they thought the minicourse was exciting and worthwhile. Pre-service teachers stated that they felt a sense of accomplishment and had more confidence in their scientific abilities. |
| E-mail journals | Although students were encouraged to document what they had learned during the minicourse in weekly journals, most students simply wrote that the minicourse was "interesting, exciting, fun, or cool." |

**Table 1. Assessment techniques used to evaluate student understanding of hydrology and attitude toward the hydrology minicourse.**

better understand the expectations of the course and how each component is interrelated.

## IMPACT OF ACTION RESEARCH

In outlining the curriculum for a two-week (10 classroom hours) hydrology minicourse, we faced the common dilemma of choosing from more available material than could be reasonably assimilated by students during the allotted time frame. We omitted material that could be easily obtained by students outside of the classroom and placed emphasis on "hands-on" experiences and inquiry-based learning activities. We tried to break down any instructor-student barriers by promoting active learning and discussion while minimizing formal lectures on course content. Instructors assisted student exploration and discovery in an attempt to dispel preconceived notions that science presents an absolute true/false duality (for example, see Perry, 1970).

In this study, our use of action research helped to (1) document the educational effectiveness of the hydrology minicourse, (2) determine the weaknesses of our approach, and (3) provide feedback for future improvement of the curriculum. By determining student pre- and post-minicourse understanding of fundamental concepts through multiple assessment strategies carried out by a diverse team, a thorough understanding of the strengths and weaknesses of the minicourse was gained. Students apparently benefitted from the involvement of a diverse instructional team that included scientists, educators, and students. Students regularly stated in e-mail journals, course evaluations, and informal conversations that having multiple perspectives during field and laboratory experiences was useful. They were also more comfortable discussing weaknesses of the minicourse with some instructors than with other instructors. Consequently, improvements of the minicourse were made based not only on our assessment strategies but from informal student-instructor conversations as well.

## CONCLUSION

Integration of field-trip and laboratory experiences was an effective learning mechanism that allowed students to make connections between field observations and more abstract hydrologic concepts. We stress that the determinant of student understanding of hydrology gained during this minicourse was not by the volume or variety of course content but by how the content was actively discovered by students in multiple learning environments. The results of this study are consistent with previous research that demonstrates field experiences attract students to science (Karabinos and others, 1992) and make science learning more meaningful (Manner, 1995). This study also adds to a growing list of studies that indicate students are more likely to understand hydrologic concepts through "real-world" experiences (Harbor and McClintock, 1993; deWet, 1994; Fletcher, 1994).

## ACKNOWLEDGMENTS

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### About the Authors

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# Miscellaneous Announcements

### A Proposal to Science Educators for Advanced Placement Geology

Geology is a science that is both fascinating and relevant to the lives of our students. Unfortunately, it is rarely offered at the high-school level. The existence of an advanced placement geology exam would encourage high schools to include geology in their curricula. Advanced placement courses are magnets that draw the best students around the country. Top science students enroll in AP Biology, AP Chemistry, and AP Physics classes. Colleges recognize the rigor of an AP course and will give preferential treatment to students enrolling in AP classes. Even if a rigorous geology course is offered in high school, the top students often avoid it because it does not carry the prestigious AP name. As a result, few college-bound students are exposed to the science of geology, and few will consider it in college. This affects both the quality and the quantity of students enrolling in college geology courses.

At this time, there is no advanced placement exam for geology. The people at the College Board believe that there is not enough interest in the exam to make it worthwhile to create the test. I am making this announcement to find out if that is the case. If you would like to teach an AP Geology course or you know someone who would, please contact me by e-mail or any other means convenient. If you or your institution would like to support this proposal, contact me as well.

Please forward this to other science educators who may be interested.

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- Synthetic and Energy-Intensive Minerals
- Value-added Industrial Minerals
- Diamonds in Canada

Field trips:

- Cordilleran geological transect with emphasis on industrial mineral deposits and operations
- Industrial mineral processing plants of the Vancouver area
- Limestone deposits of the Texada Island
- Crystar synthetic sapphire plant
- Diamond deposits of Northwest Territories
- Quaternary geology of the Victoria area and aggregate resources
- Dimension stone in Victoria

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