Using On-campus Monitoring Wells to Enhance Student Learning in Geo-hydrology Courses

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ABSTRACT

This project aimed at effective teaching of hydrologic concepts in the water sciences curriculum at the University of Northern Iowa and the State University of New York at New Paltz. The primary goal was to use outdoor instructional facilities to fill the large gap between classroom learning of concepts and its application at the watershed level. In this project, groundwater monitoring wells were set up within walking distance from the instructional buildings. Students were involved in hands-on activities, such as water sampling, on-site chemical analysis, well purging, preparing flow-nets, mapping water table contours, etc. The well clusters served as an effective intermediate step in learning hydrologic concepts. While the shallow wells were useful for unsaturated flow exercises, the deeper bedrock wells were very effective in teaching the natural hydrologic environment in the area. It was much easier for them to understand the negative impact of land use on area waters. We concluded that an on-campus or near campus instructional facility that is built in a natural field setting can bring the students a more effective experience of science. It promotes the basic elements of science inquiry among students, which includes curiosity, observation, synthesis of observed data, reasoning, and objective conclusions.

INTRODUCTION

Changing preconceptions is among the most challenging tasks that today's science educators are dealing with. It is not only a matter of making updated materials available to students, but also is an issue of presentation style and its mechanisms. The literature of science education has been flooded with innovative techniques of delivering lectures in a classroom and involving students in interactive discussions. It is only in the early 80's when hands-on activities emerged as a precondition of improved learning of undergraduate students. Nevertheless, in the recent science-education reform efforts, teachers are constantly looking for innovative ways of involving students in practical exercises in the laboratory. The objectives are two-fold: show them how science works, and involve them in meaningful activities that can change their misconceptions about science. As a result, numerous lab activity books have become commercially available in the last two decades, which include hundreds of pages of illustrations and work schedule. But, some of these lab activity books are so complex that the students get bored and become more scared of science. Indeed, field-based training of undergraduate students in environmental sciences is an area that needs to be strengthened (e.g. Andersen, 2001; Huntoon et al., 2001; Woltemade and Stanitski-Martin, 2002; Lev, 2004), because having a field perspective is the only way to understand and apply environmental and hydrogeologic principles (Weight and Sonderegger, 2002). Many environmental programs neglect field-based training in favor of computer-modeling exercises, which are abundant and commonly the only experimental hydrogeological or environmental activities offered to students (Fetter, 2001; Thorbjarnarson et al., 2002; Dunnivant et al., 2002; Woltemade and Blewett, 2002; Nicols et al., 2003).

An outdoor experimental setup (on-campus or near campus) can provide students a smooth transition from classroom learning to the real world environment. Rahn and Davis (1996) used an operational well field consisting of a main well and 14 observation wells as an educational and research facility for students at South Dakota School of Mines and Technology. They found that students had a better understanding of well hydraulics and showed much enthusiasm during these outdoor educational activities. They learned about static water level, potentiometric surface, pumping, slug and tracer tests, drawdown etc. Trop et al. (2000) successfully integrated field observations with laboratory modeling for understanding hydrologic processes in an introductory Earth-Science course at Purdue University. They took the undergraduate students to a campus water-well field located less than a mile from the classroom. The instructors first showed them the water wells that supply most of the drinking water for the university community and then generated some discussions regarding the source of the water and the physical characteristics of the aquifer. The students were then taken to a sand and gravel quarry to study Pleistocene deposits that form the uppermost part of the above aquifer. It was clear that the opportunity to visit the water-well field and the quarry removed some of their misconceptions. The students were then ready to go back to the laboratory and make their own aquifer models. Similarly, Noll (2003) showed the effectiveness of field observations in understanding hydrogeological parameters at State University of New York College at Brockport. Students were taken to a sand quarry where they observed in three dimensions the natural variations in the subsurface that would otherwise be hidden if they were to use only core samples from an unconfined aquifer. The students looked around, discussed their observation, and then collected soil samples for analysis. In the laboratory, they analyzed these samples for moisture content, bulk density, particle density, and particle size distribution. In addition, the students determined hydraulic conductivity in the field using percolation tests. The instructors found a positive impact of these activities on student learning. Numerous other investigators showed that field experiences are an important component for understanding hydrogeological concepts (Karabinos et al., 1992; Manner, 1995; Huntoon et al., 2001; Soreghan and Soreghan, 1999; McKay and Kammer, 1999).

This project demonstrates the effective use of outdoor teaching laboratory, namely two water monitoring well sites, to enhance scientific literacy in undergraduate students. The main component of the project was conducted at the University of Northern Iowa campus in Cedar Falls and was funded by the National Science Foundation and the Iowa Science Foundation. Additional activities were done at the State University of New York at New Paltz for comparison. The expenses at New Paltz were covered from their internal faculty research support program.

PROJECT DEVELOPMENT

Pedagogical Approach - Experiential learning should be an important component of undergraduate education. For instructors, factual examples facilitate effective teaching. It is not only important what students should learn, it is equally important how science concepts are taught. Appropriate materials should be used to present a scientific concept. In order to initiate their thought process, students must see the tools that are integral parts of the concept (Widnall, 1989). Appropriate teaching mechanisms can indeed change preconceptions. When learning process begins, the students naturally apply their own critical thinking set in their mind and compare the new concept to the internal structures (preconceptions) that are already present. If the new experiences don't fit their original concept, the curriculum must be flexible enough to reconsider what had been assumed and to rebuild their internal structures (Texley and Wild, 1997). Donovan and Bransford (2004) highlighted in their book "How Students Learn" the essential role of factual knowledge and conceptual frameworks in understanding complex systems, and the fact that learning is constructed on the foundation of existing knowledge and experience. Investigators reported considerable success in educating students where teaching and learning methods were used in an interactive environment (Tobin, 1993). Such an environment of teaching and learning, which is widely known as constructivism, may not be as traditional as lecture-oriented education program, but it presents strong experimental data for effective science education (Texley and Wild, 1997). Constructivism provides students with direct sensory experiences and encourages them to question their preconceptions (Clough and Clark, 1994). Subsequently, students learn how to develop hypotheses, interpret data, offer constructive arguments, and make predictions. Above all, it promotes the basic elements of science standards among students, which includes curiosity, observation, synthesis of observed data, reasoning, and objective conclusions. The whole process also allows students an opportunity of teamwork, which is a very important component of effective learning. While working on their assignments, they learn from one another to fill the gaps in their understanding of science.

Based on the important elements of science education as discussed above, the following pedagogical approach was taken in all interactive learning sessions in this project:

Scientific inquiry - The students were asked interesting questions and encouraged to respond on the basis of their collection of evidence. They were asked to work in groups, share ideas, and de-emphasize memorization.

Scientific values - The students were told that curiosity plays an important role in learning science. In the process, they were rewarded for their creativity and flexibility in ideas.

Learning anxieties - The students were encouraged to build on their success. They were given proper training in using lab equipment and were told that instruments could help them find a precise solution to scientific problems.

Dissemination - The students were encouraged to continue to explore and excel in what they do. Also, they were asked to let others know what they have learned.

TEACHING METHODS

University of Northern Iowa - We applied the teaching methods to the following three courses at the University of Northern Iowa; (i) Environmental Hydrology (15 students; juniors/seniors): The primary focus is on surface water pollution and watershed hydrology; (ii) Hydrogeology (12 students; juniors/seniors): The class teaches principles of hydrogeology, with a major focus on the principles of chemical Hydrogeology; (iii) Physical Geology (General Education course; 75 students; primarily freshmen/sophomore): The primary focus is understanding the earth's dynamic systems and its physical environments. In order to develop hydrologic concepts, a 3-step approach was taken. The methods are briefly described below.

Step 1: class lectures - The students were exposed to hydrologic concepts through detailed classroom lectures. As a part of in-class assignments, they were given written exercises dealing with Darcy flow concepts. On given diagrams, they calculated stream discharge, measured porosity/permeability, estimated groundwater resources, and studied the mechanisms of contaminant transport. They constructed flow nets and answered questions on water quality issues. All classroom activities were driven toward understanding the following concepts: (a) Groundwater is contained in pore spaces and fractures; (b) Groundwater flows from high hydraulic head to low hydraulic head; (c) Aquifers are recharged by precipitation; (d) Human activities can contaminate groundwater. (e) Groundwater quality can vary temporally and spatially; (f) Wells can serve as point sources of groundwater pollution; (g) Contaminated groundwater can pollute surface water and vice versa.

Step 2: laboratory simulation - This component involved lab activities with a groundwater flow simulation model (Mechenich, 1993). These hands-on activities were targeted toward validating the concepts learned so far in the classroom. Students performed all simulation activities under a set of guidelines from the instructor. The students were divided into groups to appreciate the importance of teamwork in science and develop self-confidence. The process of concept development was as follows:

(a) Concept: Groundwater wells can serve as point sources of pollution.
(b) Student activity: The students injected dye tracers as well as bromide and chloride-tagged waters through injection wells in the simulation system and then discharged water through pumping wells. They simulated water sampling from wells, a leaky

Figure 1. Physical Geology students at UNI getting instructions at the on-campus monitoring well site before starting their two-hour long group activities.

lagoon, and a stream that were facilitated in the model. Subsequently, they chemically analyzed the water to understand the hydrologic link among groundwater wells, rivers, and land sources of pollution. They injected colored dyes in both the confined and the unconfined aquifers in the model, monitored travel paths, and estimated groundwater velocities. Additionally, they measured hydraulic gradient of the water table in the simulation system.

(c) Follow-up discussion: Wells with cracks or rusted casings, or wells not properly sealed at the surface, can serve as conduits for farm chemicals as well as contaminated surface water to enter the aquifer and cause groundwater pollution. Notice that one of the pumping wells is contaminated with chloride only and the other is contaminated with only bromide. This is because the pumping wells are completed in two different aquifers. The clay-confining layer restricts flow between the two aquifers. Wells should be protected from damage, and should be properly sealed when they are to be permanently abandoned. Refer to state and county regulations for codes of construction, maintenance, and abandonment of wells (Mechenich, 1993).

Step 3: outdoor experimental site - The students were subsequently given access to an outdoor experimental plot in order to enhance their understanding of geohydrologic concepts. Here the students had direct access to groundwater monitoring wells and a nearby stream (called the "Dry Run Creek"). They solved varied hydrologic problems, which were based on their new concepts developed through the previous two steps.

The well cluster at UNI has 8 shallow wells (3.7 to 6.1 m deep) and 2 deep wells (22.9 m and 27.4 m). Students walked to the site during lab sessions and performed ground water as well as surface water monitoring activities. All activities were preceded by on-site discussions of well depths, types, and the drilling method (Figure 1). The shallow wells are constructed with PVC tubes in the alluvial aquifers above the pre-Illinoian till. The deep wells are metal cased and are completed in the upper Devonian carbonate bedrock aquifers. The bedrocks in this area directly underlie the pre-illinoian till. Before installing the well cluster, a formal application was filed to the Physical Facilities Planning Department at UNI to acquire this 7.6 m x 7.6 m land. The piece of land was granted in consideration of the long-term educational goals of the university. Following this, a curriculum development proposal was submitted to the Iowa Science Foundation requesting funds for the on-campus well cluster. Subsequently, the project was funded. The drilling job was then contracted out to a state-licensed driller upon approval by the university. Interested students went to the site to watch the rotary drilling procedure, which took 2 days to complete. Later, the National Science Foundation (NSF) granted additional money to conduct student activities on this site. The Dry Run Creek flows within 9 m of the well cluster, which was indeed a major factor in selecting the well site location. It gives the students an excellent opportunity to study both ground water and surface water.

The students formed teams on site and collected water samples from the wells and the adjacent creek. For the lower division undergraduate students enrolled in the Physical Geology course, the workload was less rigorous. They sampled water from the wells as well as the creek and analyzed them for pH, TDS, Conductivity, Dissolved Oxygen, and temperature. In addition, they used test strips on-site to measure chloride, nitrate, and sulfate dissolved in water. In fact, they spent much of their time in discussing their findings. The instructor was directly involved with them in dialogues as they were collecting data. The discussion sessions primarily addressed the possible sources of the dissolved materials in water. Before going back to the lab, the instructor made sure that the students understood why the chemistry of the groundwater and the stream water were different. For the upper division students enrolled in the Environmental Hydrology and the Hydrogeology classes, the workload was more rigorous. In addition to doing all the above, they used a depth indicator to measure the depth to water table and then developed a flow net in the vicinity of the well site. Then based on the flow net, they answered questions regarding well contamination. For chloride, nitrate, and sulfate, instead of using test strips the students took the samples back to the lab and analyzed them by ion chromatography. Instructor discussed with them the method of ion exchange as individual peaks appeared on the computer monitor. This was a much-needed activity for this group because most employers in the field of hydrology want applicants to be familiar with common water analytical equipment. In another day, this group of upper division students went back to the site and repeated the activities by visiting 4 other spots along the Dry Run Creek. They used their analytical kits to study water chemistry and understand how surrounding land use can contaminate stream water. They calculated stream discharge at 2 spots by measuring channel cross sections and water velocities. All activities were followed by discussions. They soon began to understand the cause and effect relationships in the hydrologic environment.

State University of New York, New Paltz - At State University of New York (SUNY), geo-hydrologic activities that were comparable to those conducted at UNI were introduced. The primary reason for replicating these activities at SUNY was to verify the results across academic institutions. Exercises were developed to integrate the theory, field data collection, and data processing. For this purpose, the hydrologic field site at the Institute of Ecosystem studies in Millbrook, New York, was used. In addition to the basic "hands-on" activities, the students conducted pump test at this site

Figure 2. Introduction to Hydrogeology students at SUNY New Paltz are conducting a pump test at the Institute of Ecosystem Studies (IES) monitoring well site.

(Figure 2). The pump test data were then used to develop a ground water flow model of the monitoring wells network site. In order to develop the model, the students used the real-world hydraulic properties of the aquifer derived from the pump test data. A 72.5 m deep ground water well was later installed on SUNY New Paltz campus in October 2004 by the US Geological Survey of Troy (USGS), New York. This well was drilled by the USGS as their ground water monitoring well network under the educational outreach program. Interested faculty at other campuses could contact Local USGS offices to explore the possibility to have free installation of on-campus ground water monitoring wells. The system of hydrologic monitoring network at SUNY, New Paltz involved several groundwater wells, a rain gauge, current flow meters for stream gauging, and tensiometers to monitor the unsaturated zone.

Unlike using a textbook or preexisting data, students used their own real world data collected in the field. They gained first-hand experiences in drilling and installing groundwater wells, designing the monitoring system as well as collecting, describing, and testing subsurface materials. They followed up first by analyzing the data they had collected, and then by modeling the actual groundwater flow. This approach helped the students understand the difficulties in building a model from scratch as opposed to textbook simulations where running the model never leads to unexpected outcomes. Students also integrated the principles and practices of surface water studies, such as sampling and monitoring, quality control and assurance, and use of water-quality equipment. They learned how to calibrate and use electrochemical probes to measure pH, specific conductance, temperature, and dissolved oxygen. The activities dealing with the hydrologic monitoring system were integrated into the courses as follows:

(a) Physical Geology (150 students): This is a general education course. Science and non-science majors were introduced to basic ground water concepts through discussions on-site. Subsequently, they measured water levels at the on-campus well site.

(b) Hydrogeology (20 students): Most of these students are geology majors. They were involved in detailed "hands-on" activities, which included determining groundwater flow direction, water quality sampling, pump tests, slug tests, and tracer tests. Much of their classroom learning was clarified through these activities.

(c) Advanced Hydrogeology (15 students): Students in this course are all geology majors who had taken most of the basic geology classes. They worked on a field based hydrogeologic site characterization exercise in this project. The exercise included determining groundwater flow direction, water quality sampling, pump tests, slug tests, and tracer tests. Students also developed a groundwater flow model of the study site using their own data collected in the field.

(d) Field Hydrogeology course (20 students): This is a 1-credit course offered in the Spring Semester every year. The course is open to students from other campuses. The field activities are usually conducted for two days over the first weekend in May. This course provides an excellent opportunity to disseminate the results from SUNY to other campuses. Students worked on hands-on exercises relating to drilling and installing groundwater wells, and then designing a groundwater monitoring system. The primary focus of this field course was to have students work in small groups of 2 or 3 in selecting monitoring well locations and installing 3 or 4 piezometers. The activities provided them with a better understanding of the shallow groundwater flow directions. The piezometers are inexpensive, which were inserted into the ground by using a large hammer.

ASSESSMENT OF STUDENT LEARNING

Evidence of improved critical thinking skills and reasoning of students were demonstrated on essay questions, and critical problem solving questions. Field-oriented realistic questions were incorporated in the subsequent exercises and their responses were evaluated. Science educators have long been in agreement that a major goal of science education ought to be fostering skills of scientific thinking (Gauld, 1982; Klauser and Alberts, 1996; Byrne and Johnstone, 1987). The students must be able to define a hypothesis, test hypothesis, and evaluate evidence (Kuhn, Amsel and O'Loughlin, 1988). The impact of the 3-step teaching approach in changing misconceptions among students in this project was evaluated, the details of which are discussed below. It was observed that in the process of discarding preconceptions, students acquired new information and then reorganized them in their existing knowledge base. In addressing this issue, the analogy between individual learning and conceptual change in scientific disciplines has always been useful in developing a suitable framework for analyzing science learning (Hewson, 1981).

Content Knowledge Test Performance by Students - One way to assess improved learning is to conduct a content knowledge test of students by incorporating some target concepts in a set of questions. The questions are given both before and after the activities are carried out. Although learning capability widely varies from one individual to another, such a test can demonstrate the general effectiveness of the given "hands on" activities. The instructor can use the result as a bench mark and then continuously revise the activities until a high improvement in learning is achieved. A set of questions were given to Physical Geology students at UNI to assess

Hydrologic Concepts	% of students responded correctly	
	Without activity	With activity
Aquifer properties	78.1	85.1
Zone of saturation	76.8	85.1
Losing/gaining stream	91.3	93.6
Confined/unconfined aquifer	88.4	93.6
Fluid pressure	82.6	83.0
Water table/Peiometric surface	76.8	89.4
Artesian pressure condition	71.0	87.2

Table 1. Improved learning of hydrologic concepts through "hands-on" activities in Physical Geology class at UNI.

their overall learning. The test consisted of seven (7) questions, each involving a specific hydrologic concept. The test was given to two groups of students. One group fully participated in all activities relating to the monitoring well site and the other group did not take part in it. The results demonstrated an improved learning of those students who took part in the outdoor activities (Table 1). The primary reason for this improvement was that each of the given hydrologic concepts was better presented to the students by using the laboratory as well as the field activities. The students were not only able to see what was being taught, but they were also able to ask effective questions and then look for an answer themselves. In every step of the learning process, they experienced how science worked.

The teaching methods applied in this project helped students develop scientific thinking skills early in their academic pursuit. Besides giving the tests, the new knowledge they acquired in hydrologic concepts was assessed by taking them to actual contaminated sites and assigning practical problems to solve. As an example, they were taken to anoxic surface water bodies and asked questions as to why the water body became anoxic and what could be done to restore them. They derived answers from the information that were provided to them on the area hydrology along with the new concepts they developed through the project activities. There were group meetings on-site, including debates and question/answer sessions. Their ultimate goal of the day was to develop learning models that could be assessed and validated by fellow students. They soon began to realize that science was not for "scientists" only, but it was for everyday people. In effect, this whole effort better prepared the students for more advanced classes.

Removal of Misconception - During a class discussion at UNI, a physical geology student mentioned that he was worried about an accidental gasoline spill near his private drinking water well. A few others commented that they were aware of similar problems in other areas. Initially, it gave an impression that the students knew that there was a link between a spill and the quality of water in a nearby well. As the discussions continued, it became clear that some of these students had a misconception. They thought that groundwater was like rivers of water in the subsurface, with rock layers above and below. It seemed difficult for them to understand that water moves through "pore spaces" of rocks. At the end of the semester, they all said that their ideas about aquifers had changed. They added that it wouldn't be possible to grasp the concept if they didn't do the porosity experiments in the lab and then actually get involved in the dye tracing experiments at the on-campus monitoring well site. Through these hands-on activities they had a better grasp of contaminant movement in porous media and their possible remediation scenarios. The "spill" example in effect dealt with changing preconceptions. As the materials were presented, the students first compared it to the preset ideas in their mind and then applied their own critical thinking to reset the concept in their knowledge pool. It is not always an easy task for the students to change preconceptions. So, the instructors should welcome questions from students and encourage them to challenge the new ideas. If the new experiences don't fit their original concept, the curricular process must reconsider what had been assumed and then attempt to rebuild the conceptual structures (Texley and Wild, 1997).

Self Perceptions of Students - Students' self perceptions of their own learning could serve as an important assessment tool. Their response to some common survey questions can tell the instructor if the teaching method is being effective. Four survey questions were given to seventy five (75) Physical Geology students at UNI to assess the success of the experiential learning activities. These were general education students and most of them did not take any geology courses prior to this class. Sixty-two (62) students returned the survey. The results of the survey are shown in Table 2. The results demonstrate that the activities conducted in this class were quite successful in enhancing the students' understanding of hydrologic processes.

Instructors' Assessment of the Project - Based on discussions with students, survey results, and course grades, the following project outcomes were assessed by the instructors:

University of Northern Iowa -

i) Hands-on activities considerably enhanced students' understanding of how science works.
ii) Students learned that groundwater and surface water are dynamically balanced and these valuable resources could be contaminated by human activities.
iii) Visits to contaminated sites played an important role in student learning.
iv) Students learned that quality of groundwater changes over time. They observed it by repeating their water analyses.
v) Exposure to analytical procedures significantly added to the students' understanding of scientific concepts.
vi) Experiential learning opportunities helped the students to change their previously held misconceptions.

State University of New York -

i) Students gained valuable hands-on experiences in this project. Without the near-campus hydrologic monitoring network this would not have been possible.

Strongly Agree (%)	Agree (%)	Undecided (%)	Disagree (%)	Strongly Disagree (%)
Question 1. The quantitative exercises on Darcy's Law, and the observed and average linear velocity were helpful to understand groundwater flow principles.				
24	70	6	None	None
Question 2. The groundwater flow simulation system helped me understand aquifer properties and understand how contaminants move through rocks.				
48	52	None	None	None
Question 3. The exercises on water table profile helped me understand the interactions between groundwater and surface water (e.g. streams and springs).				
19	66	15	None	None
Question 4. The homework assignment on flow-nets and the short tour of the on-campus monitoring well site were helpful to visualize directions of contaminant movement in aquifers under field condition.				
27	47	18	6	2

Table 2. Results of survey questions given to Physical Geology students at UNI.

ii) Student's comprehension about the hydraulic head and groundwater flow direction improved significantly.

iii) The possibility of having a hands-on experience outside the classroom stimulated the interests of introductory level students about hydrology.

iv) A senior undergraduate student got an internship with the USGS water resources division based partially on having had a field hydrology course, which utilized the monitoring network.

v) The field course associated with this project played an important role for the employment of a graduate student by the New York City Department of Environmental Conservation.

vi) The employer of one of the students considered this course as an important component of her professional training.

CONCLUDING REMARKS

The real world hydrologic environment is too big for the undergraduate students to comprehend. Although there are numerous lab books that are commercially available, they are not quite successful in demonstrating how hydrology works. Some of these lab activity books are so complex and "text book" looking that the students not only get overwhelmed and busy with activities, many get bored and more scared of science.

It is becoming increasingly clear that "hands-on" activities in an outdoor experimental set up can provide students a smooth transition from classroom learning to an environment of regional scale. It shows them how science works and involves them in meaningful activities that can change their misconceptions about science. Such an intermediate teaching resource can be developed as an on-campus or near campus open facility where the students can be taken during their regularly scheduled lab sessions. Normally it should be done as a follow up to their indoor lab activities on simulation models, stream tables, and other experimental apparatus. In fact, to get the best results, the students should be able to go back and forth between the main instructional building and their outdoor laboratory site during class periods. We observed that students don't necessarily find the content of their courses to be difficult; instead they fail to grasp the concept due to the lack of practical exercises in a field setting. The gap between indoor laboratory models and the actual processes at the watershed level is too big for them to see how hydrology works. This project showed that on-campus or near-campus monitoring well sites could fill that gap very effectively.

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