Adaptation of Groundwater Physical Models and Activities for Enhanced Student Learning

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Abstract – Studies have shown that using a variety of teaching techniques to address the spectrum of learning styles enhances student learning. The goal of this project is to improve student interest and learning of groundwater topics relevant to environmental engineering. This is accomplished by adapting physical models and real-world activities to provide students hands-on learning of groundwater concepts into the Introduction to Environmental Engineering and Laboratory courses. The target audience of this project is sophomore- and junior-level undergraduate students enrolled in these required courses. This paper presents a summary of the physical models and real-world activities developed and implemented in the courses. The models and activities are adapted from material produced by Project WET and U.S. EPA, while the implementation into courses is based on the ASCE ExCEEd teaching model.

Keywords: Environmental engineering, groundwater, active learning, models, real-world examples.

BACKGROUND AND MOTIVATION

Current trends show that a growing need exists for highly trained civil and environmental engineers. However, students often cite poor teaching as a reason for leaving engineering majors. Moreover, most teaching does not stimulate intellectual excitement because it is passive and does not place material into real-world contexts. Thus a need exists to enhance student learning through the use of effective teaching techniques that include hands-on and real-world activities that are thoughtfully integrated into courses.

The FAMU-FSU College of Engineering serves two universities: Florida Agriculture and Mechanical University, a Historically Black College and University (HBCU), and Florida State University, a Doctoral/Research University-Extensive institution. Minorities and women comprise approximately 50% of the students in the Civil and Environmental Engineering department. Thus students from underrepresented groups will be directly affected and involved in all aspects of this project. This project addresses the need for more underrepresented minorities succeeding in civil and environmental engineering. For example, according to the 2000 U.S. Census Bureau, only 9.5% of civil engineers are women. Less than 20% engineering students are female engineering, and large numbers of women who initially choose engineering change majors before earning a degree [ASCE, 1].

The overall goal of this project is to improve student interest and learning of environmental engineering, especially groundwater topics. Groundwater is selected because it is relevant to multiple areas in environmental engineering, such as hydrology, water supply, remediation, solid and hazardous waste, as well as to other civil engineering areas, such as geotechnical and transportation engineering, and has real-world applications in all these areas. In order to accomplish the goal of this project, the following tasks are developed:

1. Adapt and modify hands-on physical models and real-world active learning activities.
2. Integrate and implement models and activities in the course and laboratory.
3. Assess and evaluate the effectiveness of the models and activities in enhancing student learning.

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The target audience of this project is sophomore- and junior-level undergraduate students enrolled in the required courses Introduction to Environmental Engineering (EES 3040) and Laboratory (EES 3040L). Some students enroll in these courses only to satisfy civil and environmental engineering (CEE) curriculum requirements. However, my goal is to foster life-long interest in environmental engineering in all students so that when students become practicing civil engineers, they will consider relevant environmental engineering aspects of their work. By stimulating student interest and learning through effective teaching in introductory level courses, more students may be drawn to the environmental engineering major or at least aspects of environmental and water resources engineering.

ADAPTATION AND IMPLEMENTATION OF MODELS AND ACTIVITIES

Several physical models and real-world activities are developed and implemented in the courses. Some of the models and activities are adapted from material produced by Project WET and U.S. EPA, while the implementation into courses is based on the American Society of Civil Engineers (ASCE) ExCEEd teaching model [Estes, 2]. The focus of this project are enhancing student learning of groundwater topics, including basic groundwater definitions, groundwater flow and Darcy's law, well hydraulics, and contaminant fate and transport.

Physical Models and Activities

One physical model that was used extensively is the "ant farm" groundwater aquifer model purchased through the University of Wisconsin-Stevens Point Student Chapter of the American Water Resources Association [7]. This groundwater model shows subsurface regions and demonstrates concepts such as hydraulic gradient, pollutant transport, and the effects of pumping wells (Figure 1). Additional models include examples of soil samples from local areas, such as sands from different Florida beaches (Figure 2), well casings and screens, and piezometer probes. The purpose of these additional models is to provide students hands-on and real-world examples of materials and equipment they likely will encounter in the field.

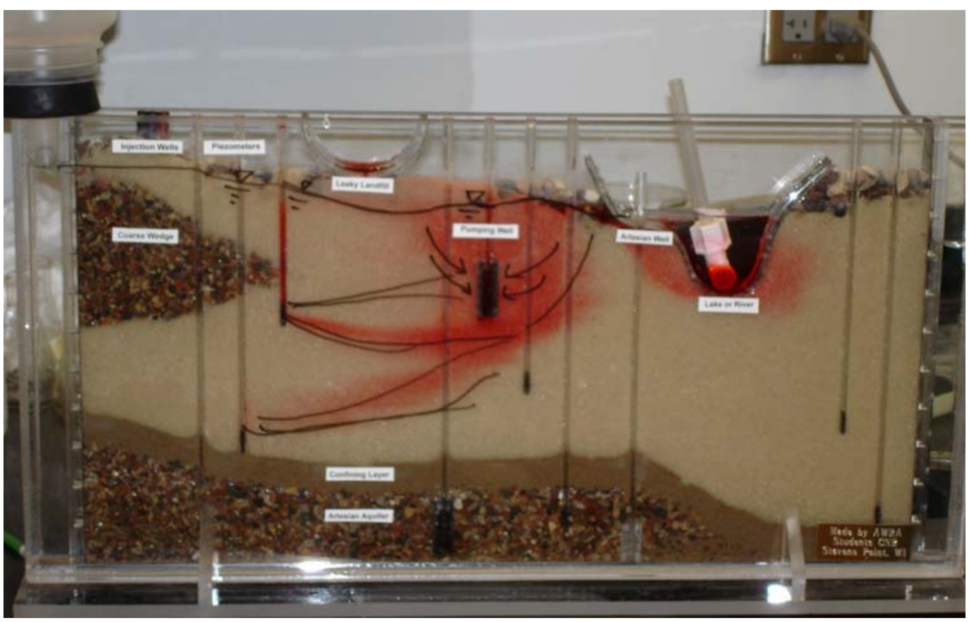

Figure 1. "Ant farm" groundwater aquifer physical model.

Figure 2. Soil samples from Florida beaches and sites.

In addition to the physical models, two group activities were developed to enhance student learning of basic groundwater contaminant transport and aquifer remediation concepts. One activity was developed based on the "A Grave Mistake" activity from Project WET [5]. In this "Investigating groundwater contaminant transport" activity, students are required to use real field data from a contaminated gasoline station site to identify the source of a petroleum plume. By using a familiar local site (in this case, at a busy intersection near campus), a real-world context is provided and students' interest is captivated. In this team-based laboratory activity, students first work with the "ant farm" groundwater model to review the groundwater contaminant transport concepts of advection and dispersion. Then the remainder of the activity focuses on the site data and map (Figure 3). Students first work together to determine the hydraulic gradient and thus the direction of groundwater flow and contaminant plume movement from the hydraulic head data at multiple sampling locations. Then each team develops a hypothesis for the source location of the petroleum plume based on limited data from 4 sampling locations. Students proceed to confirm or modify their source location by taking additional samples, in which the laboratory instructor acts as their field investigation sub-contractor and provides contaminant concentration data at the selected sampling wells. This is done in a manner similar to the popular game "Battleship." In addition, students are told that they have a limited budget for sampling and those must carefully select their sampling locations, based on the contaminant transport concepts they have learned. Once students have located the contaminant source to within a specified area, they must develop contaminant concentration isopleths (contours), which requires additional sampling.

The second group activity involves students in building their own aquifer model and exploring the efficacy of pump-and-treat remediation on several contaminant types. These include a dissolved contaminant (represented by liquid dye), a dense non-aqueous phase liquid (DNAPL) (represented by molasses), and a light non-aqueous phase liquid (LNAPL) (represented by olive oil). This "Aquifer model and remediation" activity was developed based on the "Flowing River Railroad" hazardous waste education material developed by the U.S. EPA [6]. Students work in teams to construct an aquifer model in a beaker (Figure 4). They can compare their model with other models used in class, such as the "ant farm" groundwater model. The model includes a pump mechanism and well in order to simulate pump-and-treat remediation. Students compare the movement and remediation of the three aqueous contaminant types by applying pump-and-treat to each contaminant spill. They make hypotheses regarding the difficulty or ease of removing the DNAPL and LNAPL contaminants compared to the dissolved contaminant, and then test their hypotheses.

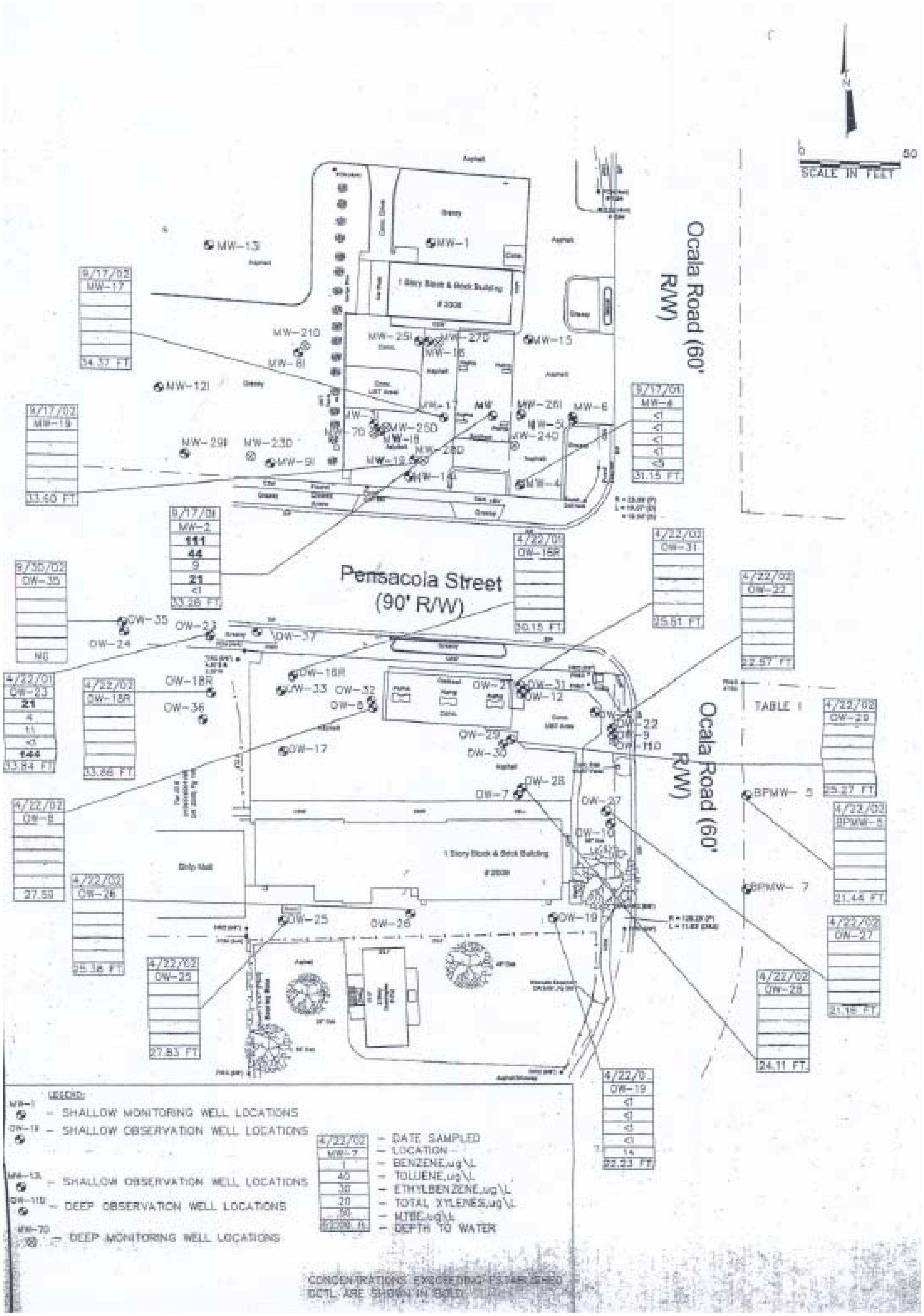

Figure 3. Site data (Tallahassee, FL) for the groundwater contamination investigation lab activity.

Figure 4. Aquifer model constructed by students for the groundwater remediation lab activity.

Implementing into Courses

The physical models and team activities developed are implemented into the courses EES 3040 and EES 3040L based on the application of the ASCE ExCEEd teaching model [Estes, 2]. The ASCE ExCEEd teaching model is based on the works of Lowman [4], Wonkat and Oreovicz [8], and Felder and Brent [3], as well as strategies used in Civil and Mechanical Engineering courses at the U.S. Military Academy. Lowman's two-dimensional model of effective college teaching is comprised of intellectual excitement and interpersonal rapport. Intellectual excitement includes clarity through technical expertise, organization, and communication effectiveness and stimulation through instructor enthusiasm, engaging students, and eliciting motivation. Active learning can be used to stimulate intellectual excitement from students. Interpersonal rapport involves the instructor demonstrating interest in student learning and in students as individuals. The ExCEEd teaching model emphasizes the use of physical models and demonstrations as well as activities that place course material into real-world context. Not only do the models and activities developed in this project stimulate student excitement for the course content, they also enhance student learning of concepts and their understanding of the interdisciplinary nature of the material and address different learning styles.

One unique aspect of this project is that student assistants are involved in developing and adapting the models and team activities. Additionally, these students are involved in the classroom, helping with the student interaction with the physical models, and leading some of the laboratory activities. Students sometimes are more interested and feel less intimidated when learning from their peers, further strengthening intellectual excitement and interpersonal rapport in the courses. The team activities are implemented in the EES 3040L laboratory. Students have the opportunity to interact with the "ant farm" aquifer model before they complete the groundwater flow and contaminant transport and remediation activities. Thus they gradually build up their level of student learning and use a variety of learning styles by the time the complete the entire groundwater module.

RESULTS AND ASSESSMENT

The effectiveness of the physical models and team activities are determined by assessing student achievement of the learning objectives for the groundwater unit of EES 3040 and EES 3040L. In EES 3040, the groundwater learning objectives are: 1) differentiate between saturated/unsaturated zones and confined/unconfined aquifers; 2) evaluate groundwater and contaminant movement using Darcy's Law; 3) apply well hydraulics to calculate drawdown and hydraulic conductivity for confined and unconfined aquifers; and 4) summarize groundwater remediation methods. In EES 3040L, the learning objectives are: 1) formulate and evaluate hypotheses for groundwater contaminant source locations through sampling; and 2) compare the movement of different groundwater contaminants by constructing an aquifer model.

Several tools are used to assess student learning of the groundwater concepts. These include a pre-quiz and post-quiz, homework assignments, exams, and laboratory reports, and anonymous student surveys. The results from the Fall 2006 semester are presented in this paper. During the Fall 2006 semester, 67 students are enrolled in EES 3040 and 66 students are enrolled in EES 3040L. Table 1 summarizes student responses from an anonymous survey given after the completion of the groundwater unit. These results indicate that the majority of students (at least 80%) found the models and team activities developed in this work to be "excellent" or "very good" in helping them learn groundwater concepts. The only activities that were rated higher are class lectures and in-class example problems (Table 1). These results indicate that the use of physical models and team activities are not substitutions to the core of a class but can be effective complements.

The anonymous survey also asked open ended questions to help indirectly assess the models and activities. In response to the question "Which in-class or lab activity did you like the best and was the most effective in helping you learn Groundwater topics?" the "ant farm" aquifer model was identified by 22 students, the groundwater contaminant transport activity by 14 students, and the aquifer remediation activity by 9 students. In response to the question "Did the extra in-class demos or focused lab activities make a difference in your learning experience?" the majority (over 90%) responded positively. However, one issue that was raised is that some students could not see the models even though two "ant farm" aquifer models were used in the classroom. This is due to the larger than usual class enrollment in a classroom that is not very well configured to handle large number of students.

Table 1. Summary of student assessment of effectiveness of activities in helping them learn groundwater concepts. Activities shown in bold font indicate the items that are the focus of this work. Data indicates the percent of students selecting a particular rating (n = 59).

	Rating				
Activity	**Excellent**	**Very Good**	**Good**	**Fair**	**Poor**
Class lectures	55.9%	33.9%	8.5%	1.7%	0%
In-class example problems	57.6%	32.2%	8.5%	1.7%	0%
"Ant farm" groundwater model	50.8%	28.8%	16.9%	3.4%	0%
Soil samples, well casing, pressure transducer	20.3%	45.8%	6.8%	1.7%	0%
Homework assignments	39.0%	35.6%	20.3%	5.1%	0%
Investigating groundwater contaminant transport team lab activity (18.6% no response)	25.4%	47.5%	6.8%	1.7%	0%
Aquifer model and remediation team lab activity (18.6% no response)	20.3%	39.0%	20.3%	1.7%	0%

The level of student achievement of the learning objectives for the groundwater unit was assessed directly through student grades and indirectly through the same anonymous survey. A pre-quiz was given which asked students fundamental questions on groundwater definitions, concepts related to Darcy's Law and well hydraulics. This same quiz was given at the end of the unit. The average pre-quiz score was 46%, while the average post-quiz score was 82%. In two homework assignments with problems related to groundwater topics, the average score was 87% for problems related to Darcy's Law and groundwater flow (Learning objective 2) and 93% for problems related contaminant movement and well hydraulics (Learning objectives 2 and 3). In a multi-unit exam, the average score was 93% for questions related to subsurface regions and remediation (Learning objectives 1 and 4) and 91% for questions on groundwater and contaminant movement and well hydraulics (Learning objectives 2 and 3). Table 2 summarizes student perception of their level of achievement of the learning objectives obtained through the anonymous survey. The results indicate that students are very confident of their level of achievement of learning objective 1, as confirmed by quiz and exam scores. Students are also confident in their ability to achieve learning objective 3, with more than 78% students rating their achievement as “excellent” or “very good.” This also is confirmed by homework and exam scores. Moreover, students were confident with their achievement of the two lab learning objectives (Table 2). While with high ratings (at least 52.5% of students assessing their achievement as “excellent” or “very good”), students did not feel they met learning objectives 2 and 4 as well.

Table 2. Summary of student assessment of their level of achievement of the learning objectives (n = 59).

	Rating				
Learning Objective	**Excellent**	**Very Good**	**Good**	**Fair**	**Poor**
1. Differentiate between saturated/unsaturated zones and confined/unconfined aquifers	61.0%	30.5%	5.1%	3.4%	0%
2. Evaluate groundwater and contaminant movement using Darcy's Law	37.3%	35.6%	25.4%	0%	1.7%
3. Apply well hydraulics to calculate drawdown and hydraulic conductivity for confined and unconfined aquifers	37.3%	40.7%	18.6%	1.7%	1.7%
4. Summarize groundwater remediation methods	18.6%	33.9%	40.7%	6.8%	0%
Lab1. Formulate and evaluate hypotheses for groundwater contaminant source locations through sampling (18.6% no response)	22.0%	47.5%	10.2%	0%	0%
Lab2. Compare the movement of different groundwater contaminants by constructing an aquifer model (16.9% no response)	23.7%	44.1%	13.6%	1.7%	0%

CONCLUSIONS

Overall students achieved the learning objectives and students gave positive evaluation scores for the models and activities developed in this work. In particular, students liked the hands-on and visualization opportunities that the models and activities provided them. They also liked the real-world example of groundwater contamination investigation and the use of actual field data in the “Investigating contaminant transport” team activity. Future work will address improvements to these models and activities and their integration into lessons. Moreover, material will be modified to help students better achieve lesson objectives 2 and 4, which are related to Darcy’s Law concepts and groundwater remediation methods. Additional site data will be identified to build a library of data sets that can be used for the activities.

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