Groundwater Interactive: Interdisciplinary Web-Based Software Incorporating New Learning Methodologies and Technologies

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Abstract

Groundwater related courses are offered through several colleges at Virginia Tech. These classes enroll a diverse group of students with varied academic backgrounds and educational levels. Though these classes emphasize different aspects of groundwater resources, they lack a unified approach in instructional materials and learning methodologies for knowledge they do share. The goals of this research are to lessen the impact of variable student backgrounds and to better integrate the courses to improve teaching and learning, through the development of a multi-tiered, interdisciplinary website, Groundwater Interactive (GWI). GWI, as an educational technology, employs a variety of interactive multimedia. The primary educational components of the website include interactive and graphical models and quizzes, and a student-authored primer. An implementation strategy based on experiential and cooperative learning models is developed for application of the GWI tool in the classroom. An assessment methodology to evaluate the effectiveness of these new learning methods and techniques was also developed, but was not implemented as part of this work.

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Table of Contents

List of Figures

Introduction

A framework was initiated for improved learning in cross-discipline, groundwater courses, through the development of an interdisciplinary website incorporating new learning methodologies and technologies.

Groundwater accounts for close to 70% of the available fresh water resources on earth. It is therefore not surprising that this vital resource is studied in several departments and colleges at Virginia Tech. A recent growth of employment in these areas has attracted a large number of students from a wide variety of backgrounds. On average, between 200 to 250 students per year enroll in groundwater courses across three departments. A typical class will merge students with different academic backgrounds and educational levels.

The study of groundwater hydrology and remediation requires the ability to integrate chemistry, biology, and physics, through quantitative problem solving skills. However, the instructional materials for groundwater related courses in these departments lack a unified approach. Current courses in groundwater at Virginia Tech emphasize different aspects and perspectives, and have stringent prerequisites. They are all highly analytical and technical, requiring students to assimilate abstract concepts.

Goals of this research are to lessen the impact of variable student backgrounds and to better integrate the current groundwater related courses to improve teaching and learning. This can be accomplished through the incorporation of interactive multimedia as an educational technology, and through the implementation of experiential and cooperative learning techniques. Specific objectives of this research project were as follows:

- Develop software models, specifically for educational purposes, which include a high degree of user interaction and graphical visualization.
- Develop quizzes, incorporating interactive review and problem-solving, which provide learning through feedback and guidance.
- Develop collaborative, student-authored, multimedia-enhanced webpages, which can also serve as a learning resource to other students.
- Develop an interdisciplinary website and implementation strategy to integrate the previously mentioned goals and objectives.
- Develop an assessment methodology that can be used to evaluate the effectiveness of the learning methods developed above.

Methodology

Groundwater Interactive (GWI) Described

Traditional Teaching/Learning Environment

Curriculum

Curriculum in the areas of groundwater hydrology/hydraulics, pollution and of groundwater contaminant transport is interdisciplinary in nature. Related courses are taught in the Departments of Civil and Environmental Engineering, Geological Sciences, and Crop and Soil Environmental Sciences. All courses are either advanced undergraduate or graduate level, and emphasize different aspects and perspectives. Related courses and descriptions follow:

GEOL 4114 Groundwater Hydrology: Physical principles of groundwater flow; Sources, occurrence, inventory, utilization, and recharge of ground water in the earth's crust; Groundwater and geologic processes.

CEE 4314 Groundwater Resources: Groundwater hydrology; Aquifer properties; Steady and unsteady flow in both confined and unconfined aquifers; Well flow equations; Groundwater resource evaluation and development; Design of groundwater recovery systems; Introduction to groundwater modeling.

CEE 4594/CSES 4594 Soil and Groundwater Pollution: Application of mathematical models for chemical movement in soils and groundwater to evaluate soil and groundwater pollutant behavior; discussion of pollution remediation technologies; design of subsurface monitoring networks; case studies in soil and groundwater pollution; applications to landfills, waste spills, septic drainfields, pesticide/fertilizer leaching, and other problems of environmental concern.

GEOL 5804 Quantitative Hydrogeology: Mechanics of groundwater flow in one and multi dimensions. Application of initial and boundary conditions in solving analytical problems to vadose-zone and saturated flow systems. Fractured flow and Biot theory problems are introduced. Well hydraulics.

CEE 5374 Dynamics of Groundwater: The theory of dynamics of fluids in porous media; groundwater modeling; transport equations; boundary and initial value problems; flow of immiscible fluids; dispersion.

CEE 5354/GEOL 5814 Numerical Modeling of Groundwater Flow and Transport: Theory and practice of numerical techniques for development and application of fluid flow and transport problems. Model conceptualization and design in multidimensional systems. Practical applications of models including calibration, validation and prediction. Use of MODFLOW , MODPATH, and MT3D.

Enrollment and Special Considerations

These courses attract students from a variety of programs and are all heavily enrolled. Courses are either advanced undergraduate (senior 4000) or graduate level, and within separate departments emphasize different aspects and perspectives. Enrollment, therefore, represents a population of students from a wide variety of backgrounds with different educational histories and objectives, and varied age and maturity levels. Class composition ranges from undergraduates to PhD candidates, and incorporates 'scientists' from some departments and 'engineers' from others. In addition, CEE 4594 / CSES 4594 and CEE 5374 are part of the MS Civil and Environmental Engineering curriculum offered through the Distance Learning Program. When offered through the Distance Learning Program, an additional 50-100 students per semester are typically enrolled. The majority of these students are 'nontraditional' and represent professionals in the workplace pursuing continued education. Statistics for available classes are provided below. Figure 1 shows enrollment for selected classes. Figure 2 shows student background represented by enrollment per department. Figure 3 shows student background represented by enrollment per academic level.

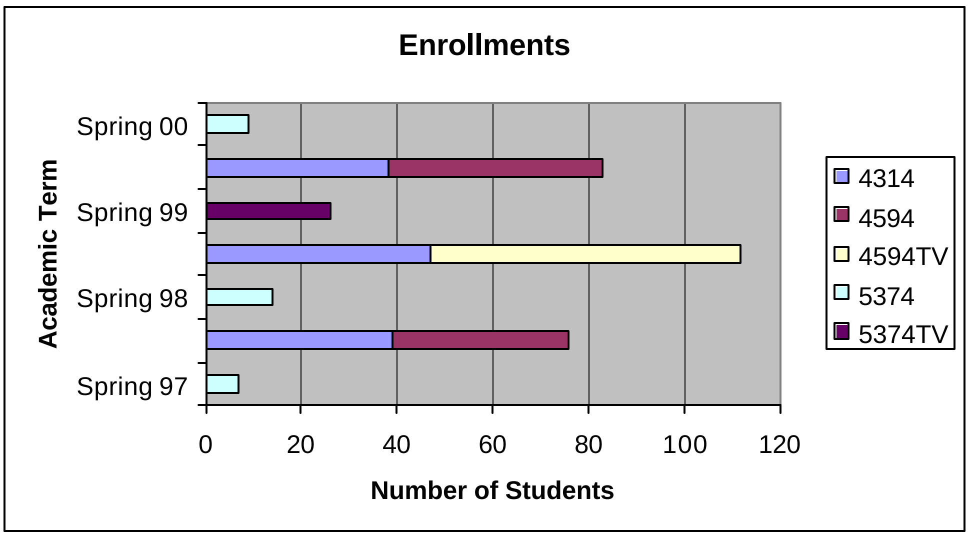

Figure 1. Class Enrollments

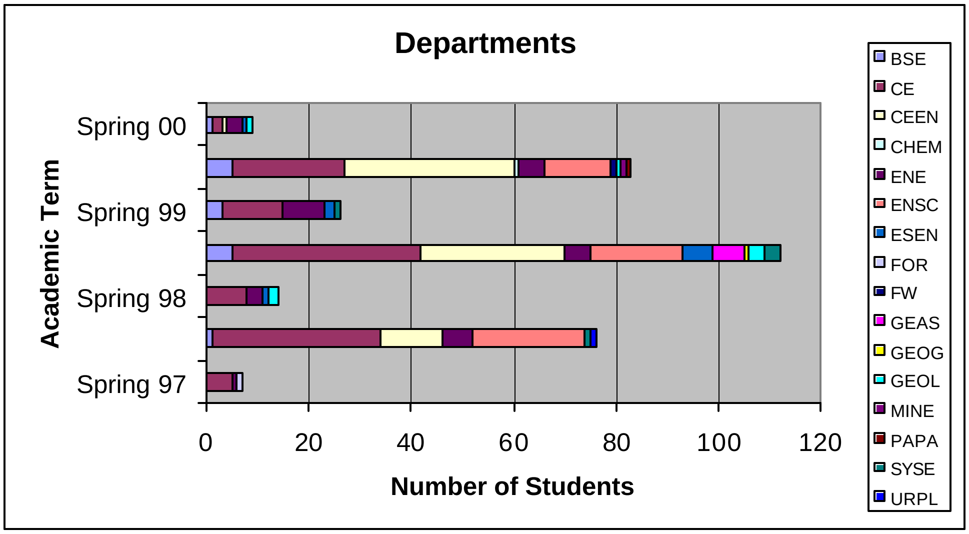

Figure 2. Student Background: Departments

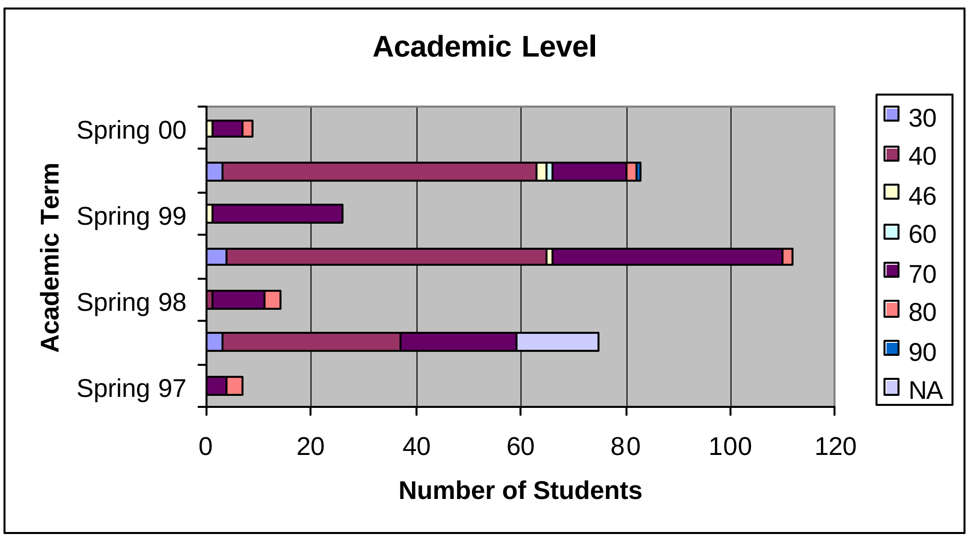

Figure 3. Student Background: Academic Level

Traditional Pedagogy

Traditionally, learning of the fundamental principles of groundwater hydrology and remediation has been in a teacher directed learning environment. This pedagogy is primarily didactic lecture based and textbook driven with structured presentations of curriculum material. Being associated with structured knowledge, this pedagogy is appropriate for introductory experiences when the purpose is to: disseminate information, present material that is not available elsewhere, expose students to content in a brief time that might take them much longer to locate on their own, and arouse students' interest in the subject. This traditional method of college teaching relies on these basic principles: Students are considered passive learners, in that they are merely expected to memorize and recall knowledge that is transferred to them; Students are classified and sorted into categories in a norm-referenced way depending on which grade they should get and whether or not they have met requirements; A competitive environment causes students to work to outperform their classmates; And the learning process takes place within the context of impersonal relationships between students and their peers (Johnson et al. 1991).

Groundwater Interactive

Reason to Use / Changed Pedagogy

Professionals entering today's job market need to have attitudes and abilities that permit them to independently identify and solve problems, and to communicate results to others. They also need to have skills for collaboration with people who are alike and different from them. Employers want a 'totalist' who can bring specialized skills to teams, retrain when needed, collaborate on projects, and overlap skills and knowledge with other disciplines. To solve problems in the workplace, professionals must have the ability to work with others to plan and carry out applied research. Graduates will need to integrate information from a variety of subject areas, ask questions that identify and solve problems, collaborate with interdisciplinary teams, and use technology to develop and communicate concepts. Such skills are promoted when instructional methods are used that involve students as partners in problem based learning activities.

Though lecturing has positive points as mentioned in the previous section, it is usually not responsive to the interdisciplinary concerns of the 'totalist', in that students primarily have less freedom, become passive learners, have limited opportunities to generalize concepts to applied settings, and problem-solving abilities may be poorly developed (Hancock and Belts 1994; Schlager et al. 1999). Problems with the traditional lecturing methodology are: students attention to what the instructor is saying decreases as the lecture proceeds; it takes a person oriented toward auditory learning to benefit from listening to lectures; tends to promote only lower level learning; it is based on the assumptions that all students need the same information presented at the same pace; lecturing is what students tend not to like; and it is based on a series of assumptions about the learning capabilities and strategies of students (Johnson et al. 1991). Many teachers assume that all students learn the same way so they teach in their own individual style without consideration for differences among students. This may cause students to experience discontinuity with their diverse experiences, knowledge and learning styles. This inability to adapt to different learning styles may be a factor for poor academic achievement (Davis 1996).

"A survey of teaching methods suggest that if we want students to become more effective in meaningful learning and thinking, they need to spend more time in active, meaningful learning and thinking, not just sitting and passively receiving information. Getting students cognitively, physically, emotionally, and psychologically involved in learning is an important step in turning around the passive and impersonal character of many classrooms." (Johnson et al. 1991). A more open approach, incorporating experiential and cooperative learning techniques, is associated with higher cognitive functions such as problem-solving, provides freedom for student expression, input, and response, encourages team-building and collaboration skills, and is more appropriate for higher level, advanced undergraduate or graduate courses (Hancock and Belts 1994; Schlager et al. 1999).

Experiential Learning

The current work environment demands that employees have the ability to not only work on their own but also in multidisciplinary teams. Disciplinary studies may be better suited to younger, traditionally aged learners, or to those interested in specific research areas. Research has shown that the diverse students within our interdisciplinary classes are more likely to benefit from interdisciplinary studies and from the experiential methodologies and interactive technologies often used to support those studies (Dinmore 1997). Kolb's objective was to develop an educational methodology to meet the needs of the new diverse student populations. "Kolb's model bases the curriculum on experiential learning to allow the development of an integrative and non-disciplinary body of knowledge from the variety of experiences brought into today's classroom." (Katula and Threnhauser 1999).

Experiential learning theory, developed by Kolb, is a holistic integrative perspective on learning that combines experience, perception, cognition and behavior. The process of experiential learning is a cycle involving four adaptive learning stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation (See Figure 4.

Kolb's Experiential Learning Model (modified from Kolb 1984)). The concrete / abstract dimension represents the grasping of knowledge, either feeling (tangible, felt qualities of immediate experience) or thinking (conceptual representation and symbolic representation). The reflective / active dimension is one of transforming knowledge, either watching (internal reflection) or doing (active external manipulation). The learning process depends upon transactions among the four stages and the how the dimensions are resolved. A higher level of learning, therefore, results from the combination of grasping knowledge and transforming it (Kolb 1984).

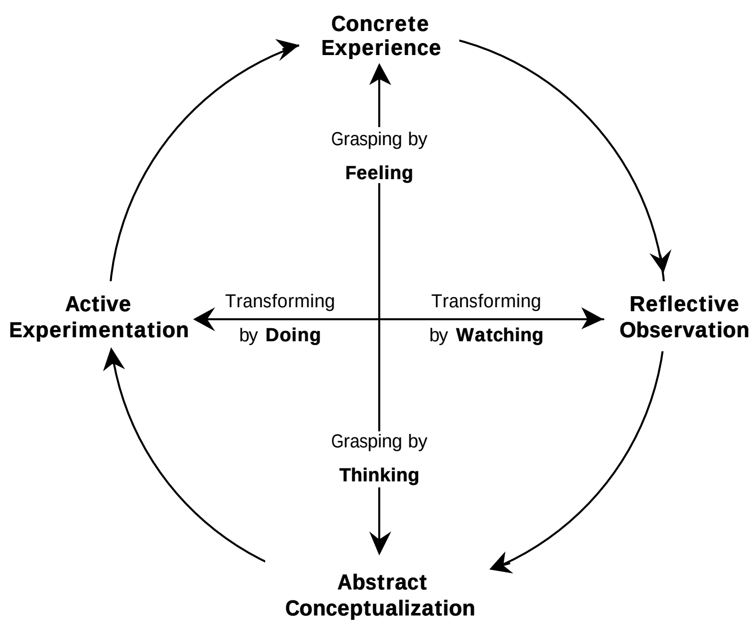

Figure 4. Kolb's Experiential Learning Model (modified from Kolb 1984)

Cooperative Learning

Experiential education compared to other instructional methodologies has a higher motivational value that stimulates student involvement, especially if performed in cooperative groups. "While most real world tasks are cooperative in nature due to their complexity, time constraints, or requirement for broad experience, cooperative learning is rarely incorporated into the educational classroom. Cooperative interaction in the classroom has been shown to change the traditionally passive learning environment created by lecturing, to one in which students become more cognitively active." (Johnson et al. 1994b). Compared to competitive and individual learning methodologies, cooperative learning proved more beneficial by: promoting higher achievement; developing critical thinking and reasoning, positive attitudes towards learning, interpersonal skills, and self-confidence; and by developing interpersonal relationships that provide a network useful to students later in their careers (Johnson 1999; Schlager et al. 1999). Complementary research has shown benefits of the cooperative learning methodology to include: students benefit from different perspectives on the material, leading to deeper understanding; the group brings with it a broader range of experience than any one individual; by communicating what they have learned to others, their learning can lead to broader application of the material; a sense of involvement and identification in groups is developed, supporting the need to interact with others (Chou and Sun 1996). This methodology replaces the mass production, competitive, organizational structure of most classrooms with a team-based, high-performance organizational structure. Cooperative learning helps raise the achievement of all students involved, with involvement being extremely high because of the freedom to synthesize and gather information that is meaningful to them. This methodology gives the student the ability to develop team-working and problem-solving skills as a result of group dynamics (Schlager et al. 1999). "It helps build positive relationships, which is the heart of creating a learning environment that values diversity, and gives students the experiences they need for healthy social, psychological, and cognitive development." (Johnson et al. 1994a).

Cooperative learning is the incorporation of small groups in which students work together to not only maximize their own learning, but each others' learning as well. In the cooperative learning philosophy: all individuals are given the opportunity to learn in many different ways and at varying rates; all individuals are given recognition for their achievements; all individuals are recognized as both learners and teachers; the learning environment is characterized by interdependence and diversity (Davis 1996). Teaching should be based upon the cooperative learning principles in which: knowledge is constructed, discovered, transformed, and then extended by students; students actively construct their own knowledge; faculty effort is aimed at developing students competencies and talents; education is a personal transaction among students and between the faculty and students as they work together (Johnson et al. 1991).

The basic components of cooperative learning are; positive interdependence, promotive interaction, individual accountability, use of interpersonal and small group skills, and group processing. See Figure 5 for the basic components of cooperative learning and their relationships with one another. Two types of cooperative learning groups are; formal learning groups, and informal learning groups.

Positive interdependence enables students to see that each group members' work benefits each other member. Small groups maximize the learning of all members by allowing shared resources, and providing support and encouragement. Each group member realizes that his or her role, resources, and responsibilities are required and indispensable for group success.

Promotive interaction is a result of positive interdependence and occurs with members encouraging and facilitating other members' efforts to reach team goals. This aspect of cooperative learning increases efforts to achieve, develops healthy interpersonal relationships, and enhances psychological adjustment and social competence.

Individual accountability assesses the performance, within the team environment, of individual group members. This method ensures that all group members benefit from learning cooperatively, and are held responsible for contributing an equal share to the group.

Group processing identifies and improves group members' effectiveness in cooperative efforts to achieve group goals. This process reflects on a group session to describe what actions were helpful and unhelpful, and to decide what actions should be continued or changed.

Interpersonal and small group skills are developed as a necessary part of team function. To achieve group goals, members must trust and support one another, communicate clearly and effectively, and resolve group conflict in a constructive manner.

Formal cooperative learning groups involve group members working together from one class period to several weeks, to achieve shared learning goals and complete specific tasks or assignments.

Informal cooperative learning groups involve group members working together temporarily from a few minutes to a class period to achieve a shared learning goal.

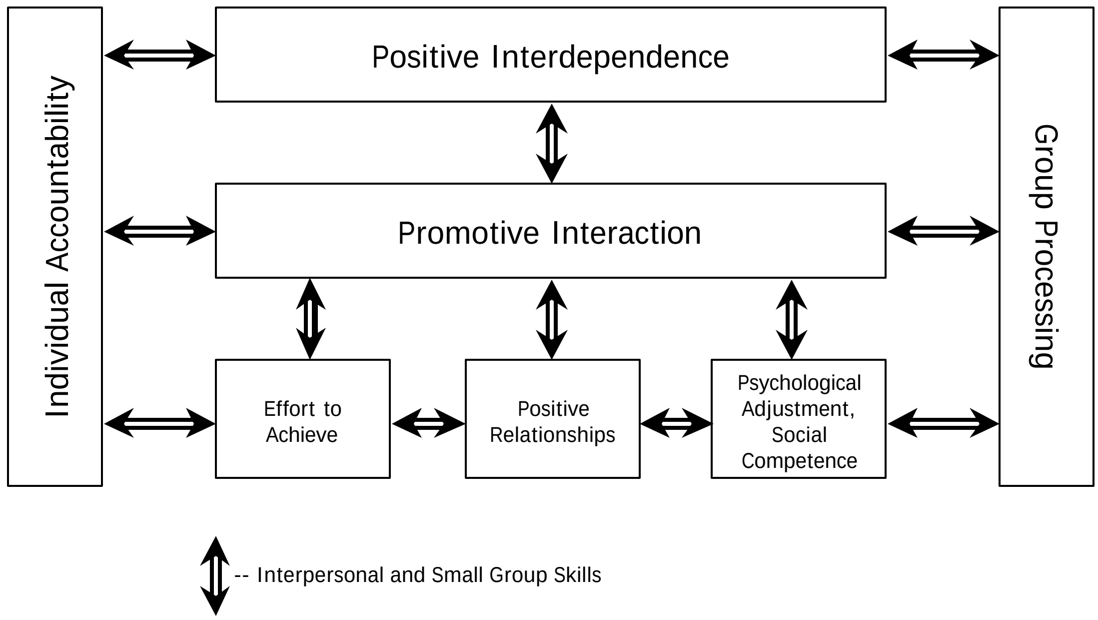

Figure 5. Basic Components of Cooperative Learning

Educational Technology

The use of technology in college teaching is increasing rapidly. Technologies such as web-based interactive multimedia are changing the educational paradigm. Multimedia has been used to describe a wide variety of computer based systems, primarily those integrating audio and video with conventional text, still images, animations, other graphics, etc. The World Wide Web has become an excellent host for multimedia, by providing improved tools, interactive functionality, and broader bandwidth. Web oriented programming languages allow the ability to create applications that can include interactive multimedia elements. Multimedia placed on the web, provides for self-directed, self-paced learning and can be accessed at various times and places suitable to both teacher and learner (Charp 1997).

There has been extensive research conducted on the effectiveness of computer-based education. Research shows that with the use of educational technology, substantial benefits may be expected in the areas of: content, curriculum, and pedagogy enhancement; student preparation for the labor market; and university program competitiveness. Research specifically reveals that computer-assisted instruction is equal or superior to traditional instruction in the following aspects: student achievement with both short- and long-term retention; attitude toward the material and the instructor; and time to complete tasks. These students attain higher achievement in significantly less time, perhaps around 20% or more on average, than traditionally educated students (Cartwright 1993; Ehrmann 1995; Green and Gilbert 1995). "A particular study found that students using multimedia materials scored significantly higher than those using traditional text materials after two hours of exposure to the material; the multimedia group also expressed positive reactions to the experience, whereas the text group found the instruction boring." (Halpern 1994).

The most common use of computers in education involves individual students using software that drills on basic skills learned in class. This practice lessens interaction among others and does little to promote the development of higher order thinking. However, web-based multimedia applications can provide a community that fosters cooperative learning. "Studies indicate that cooperative learning teams working with computers show an increase in achievement over those students engaged in competitive work or individualized learning involving computers." (Halpern 1994). In a comprehensive collection of research on web-based technology, researchers have concluded that this technology changes the educational paradigm by enhancing these aspects of the learning experience: project- and team-based instruction, distance learning course delivery, use of simulations and scenarios, reaching hidden voices in the classroom, learning self-discipline, research collaboration, and cooperative learning (Tang and Johnson. 1999).

Motivation

The use of experiential learning theory, cooperative learning methodology, and educational technology must also include the important element of motivation. Experiential learning does not take place unless the student is willing, and desires to move through the learning cycle. To inspire the active involvement component of experiential learning, the learner must be motivated, extrinsically or intrinsically, to engage in the learning experience (learning will be more enthusiastic if the student is intrinsically motivated), and the learner must be legitimized (relevance is needed for learning to have a lasting effect). Two conditions must be present for motivation to be strong in the student. First, the learner must recognize the personal lacking of what is to be learned, and secondly, the learner must believe the knowledge will enhance the achievement of personal goals. When these two conditions exist, strong motivation takes place and the learner becomes focused on acquiring the new knowledge. The object, therefore, is for educators to identify and incorporate ways to maximize motivation in students at the beginning of the process (Burns and Gentry 1998). Figure 6 shows the new teaching/learning scheme and the relationships between experiential learning, cooperative learning, educational technology, and motivation.

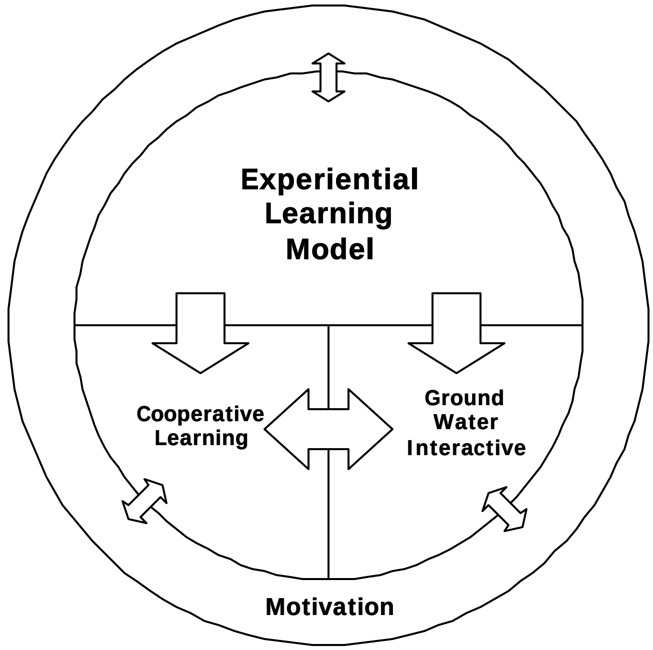

Figure 6. EL-CL-ET-Motivation Scheme

Development of GWI

Ground Water Interactive (GWI) is a joint effort from faculty and students in the Departments of Civil and Environmental Engineering, Geological Sciences, and Crop and Soil Environmental Sciences. Those with direct responsibility include: Dr. Daniel Gallagher, Associate Professor, Civil and Environmental Engineering; Dr. Mark Widdowson, Associate Professor, Civil and Environmental Engineering; Dr. Naraine Persaud, Associate Professor, Crop and Soil Environmental Science; Dr. Thomas Burbey, Assistant Professor, Geological Sciences; and the author of this thesis, Eduardo Mendez, Graduate Research Assistant, Civil and Environmental Engineering. The Ground Water Primer is authored by students in CEE 4594/CSES 4594 Soil and Ground Water Pollution. The four faculty members involved actively teach the previously listed courses. Each is currently posting notes and other class materials to the web. Drs. Gallagher and Persaud have run pilot versions of the student-authored primers since the 1996-1997 academic year. All the faculty actively develop groundwater models as part of their research areas and incorporate commercial software in their courses.

Because ground water courses at Virginia Tech attract students across disciplines and colleges, and because different students learn differently, GWI was developed as an interdisciplinary, web-based, multimedia application to provide an interactive teaching and learning environment for multiple groundwater courses. Through the organization and content of GWI, students can achieve different levels of development and learning, enabling them to manipulate GWI to address their own teaching / learning situations. GWI helps bridge the gap between classroom theory and real-world applications by giving students experience in applying the concepts learned in class to simulate groundwater problems. (Yarbrough and Gilbert 1999).

While GWI relies heavily on internet technology, it may also be used as a stand-alone teaching tool. The entire website may be loaded onto a hard drive and used in the classroom, or at home, with no connection to the internet. GWI may therefore be used as a multimedia presentation tool or home learning tool without an active internet connection. Both Microsoft and Netscape advocate that browsers be used for stand-alone applications, with Hypertext Markup Language (HTML) as the language (Tang and Johnson 1999). HTML is the standard language for describing the contents and appearance of pages on the World Wide Web. This is because the HTML interface is user-friendly. Aside from hyperlink capability, HTML can be used to create graphical user interfaces (GUIs). GUIs are inexpensive and easy to create, can be easily modified and debugged, and are naturally easy to use and learn. The internet browser and its hypertext capability is a powerful teaching tool that allows the organization and presentation of information in an efficient and effective way. The browser capability allows the teacher to locate and present a fixed amount of material in a way that is more flexible to the needs of the class being taught.

The development of the software includes analysis, design, production, evaluation, and revision phases. Goals included determining GWI objectives, analyzing learning tasks, and collecting the required learning materials. Technological issues included hardware, software, data-transfer techniques, protocols, applications, security, management and maintenance. Learning materials and multimedia components were identified and organized for each area of GWI. A website format was designed, and storyboards for each section were created to help visualize the merger between information and multimedia. In the production phase of GWI, the multimedia components were developed and then written in HTML format (Chou and Sun 1996). Works that influenced the content of GWI were numerous and diverse. The content material originated in various formats and required conversion to the HTML format. These documents were manually converted using MSWord as HTML conversion software. NetObjects Fusion and Microsoft Front Page were used as HTML development environments. Modules were tested throughout the development period by several individuals and were revised accordingly prior to initial implementation.

GWI contains a wide variety of multimedia components, developed on a wide variety of systems. Multimedia components include: reading text, hypertext (interacting with one bit of text can lead directly to different text (or other media) located elsewhere, images, drawings/paintings, animations, photographs, graphs, movies, sound, links. Hypertext is nonlinear or nonsequential text incorporating the thread capability, whereby items in a document are linked to the location of a document section located elsewhere. Compressed sound files work well to store talks on the pros and cons of a particular technology. Video or animations can be useful visualization tools used to display simulations of contaminant plume transport, etc. Links allows access to materials outside GWI's domain, permitting users to explore the resources of sites having materials relevant to groundwater topics.

The design begins with a homepage, shown in Figure 7, that provides access to the main components of GWI (http://www.cee.vt.edu/program_areas/environmental/teach/gwi/index.html). GWI incorporates a three-tier learning approach based upon three major sections; models, quizzes, and primers. The **Models and Software** page includes a variety of graphical and interactive models for educational use, as well as links to public domain models. The **Quizzes** page is a series of multiple-choice questions dealing with ground water hydrology and pollutant transport. The **Ground Water Primer** is a set of student-authored web pages concerning contaminant transport and remediation. Other sections include; **Courses** link to the ground water courses currently taught at Virginia Tech. **Authors** describes the creators of and contributors to Ground Water Interactive. **Links** are available to external ground water sites that are of interest to students.

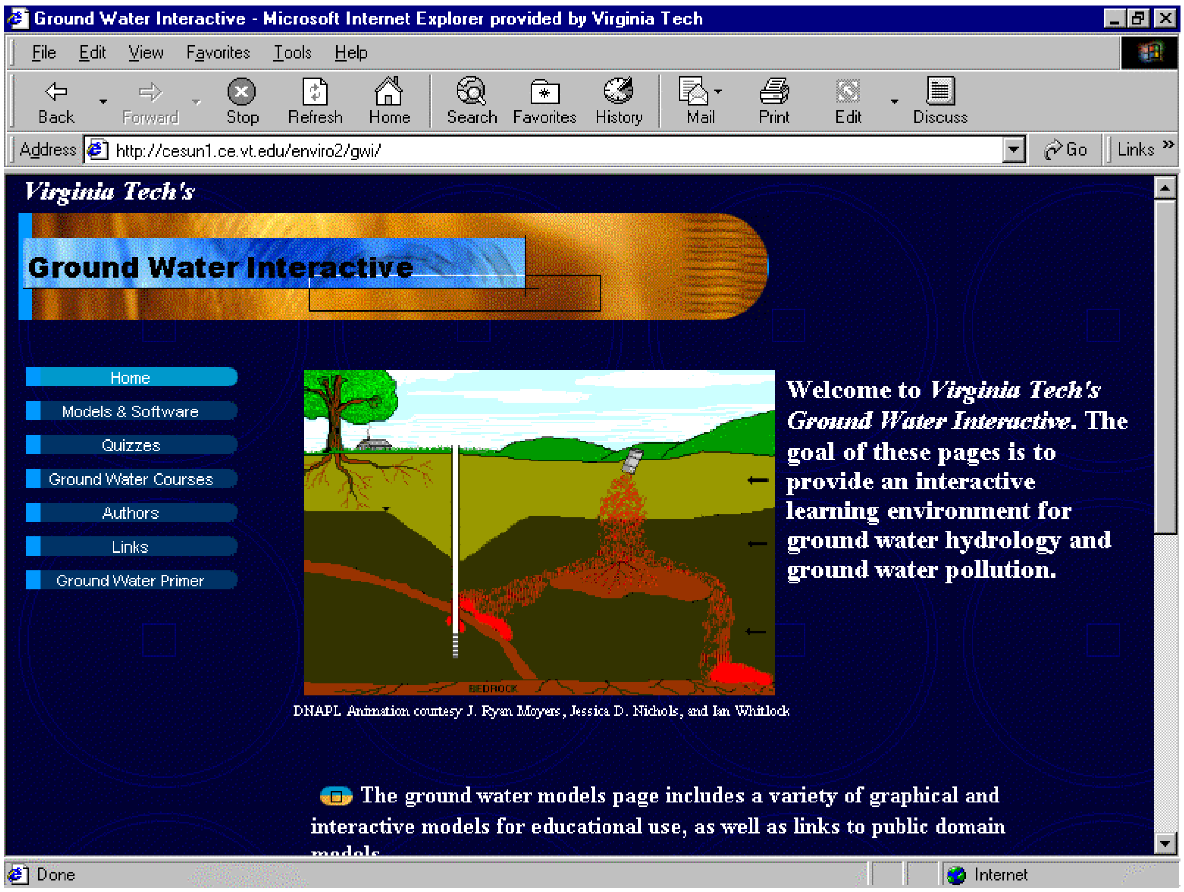

Figure 7. Ground Water Interactive HomePage

Models

The first approach is based on a series of groundwater hydrology and contaminant transport models developed within the Microsoft Visual Basic environment and incorporating MS ActiveX technology. ActiveX technology allows the development of components that enable interactive content for the World Wide Web. Through ActiveX, Web sites can use multimedia effects, interactive objects, and sophisticated applications to create an interactive user experience. These ActiveX models emphasize interaction and visualization, while teaching the important aspects of commercially available groundwater models. GWI currently offers five contaminant fate and transport models. Each is described briefly below. All models are Windows-based with setup programs available for download. For users of Microsoft Internet Explorer, all of these models may also be run directly from your browser using MS ActiveX technology. Additional models will be added as developed.

Contaminant 1D: The goal of this program is to graph the analytical solution to the advective-dispersive contaminant transport equation for ground water flow (See Figure 8). The model assumes a homogeneous, 1-dimensional aquifer. Either the concentration profile with distance, or the concentration profile with time can be graphed. The model is useful for explaining critical concepts in contaminant transport with inputs including distance or time, average linear velocity, dispersion coefficient, retardation factor, decay rate, and duration of the release. The model assumes a contaminant release over a fixed duration. To model a continuous release, set the duration to be greater than the time on the graph. Although the duration can be set quite low, the model is not designed to handle an instantaneous spill. Students set the values of the input parameters using sliders. Changes to the inputs can be made simply by sliding the appropriate parameter's slider bar up or down. Boxes at the top and bottom of the sliders can be used to set the range for each parameter. The blue number underneath the slider shows the parameter's value. If the retardation factor is set greater than 1, or the decay rate is greater than 0, two predicted curves are shown to illustrate the impact that these mechanisms have on the concentration profile. The curve in red is for the contaminant with sorption and decay. The curve in blue is for a nonsorbing, nonreacting contaminant. As the slider moves, the pollutant profile output graph is automatically redrawn. This approach allows for the rapid visual evaluation of a wide variety of options and helps to gain a better understanding of the importance of the model parameters, allowing the sensitivity of the predicted concentrations to be easily assessed. The graph can be switched from plotting concentration vs. time to plotting concentration vs. distance with the click of a button. Different types of boundary conditions can be examined as easily. The displayed graph can be printed through a menu command.

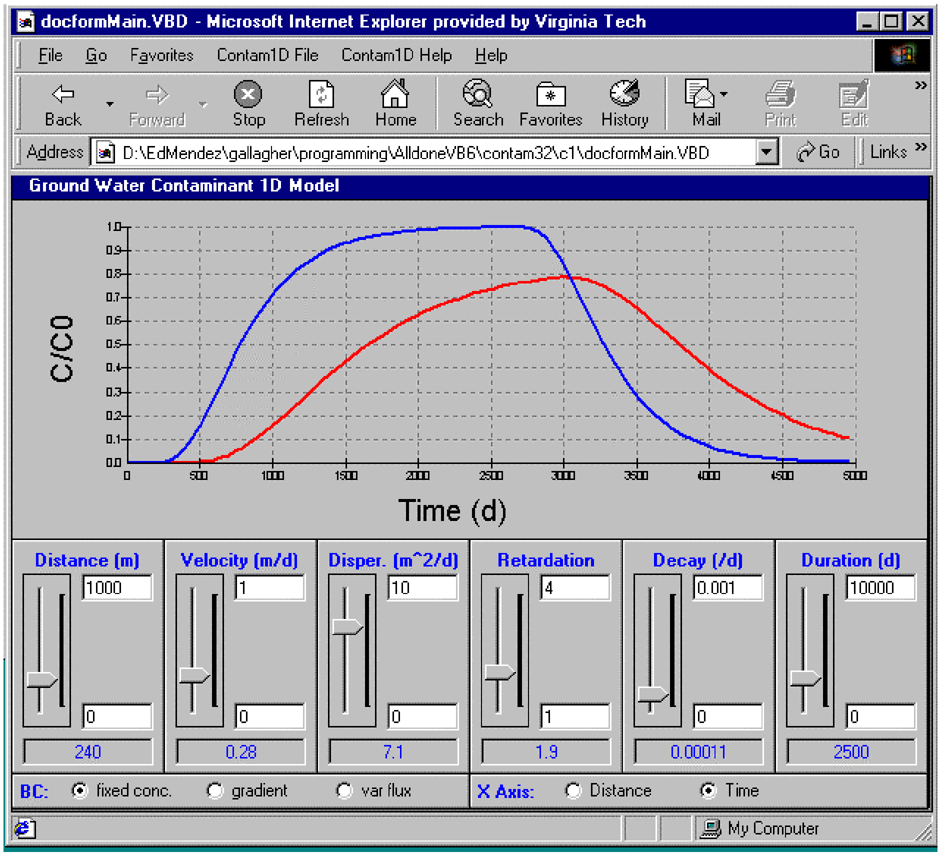

Figure 8. Contaminant 1D Model

Random Walk: This application is a dynamic, two-dimensional groundwater contaminant transport model with graphical interface that tracks particles of contamination. The model is based on the Random Walk approach described in various groundwater textbooks (Charbeneau 2000). Model assumptions include; a homogeneous, 2-dimensional aquifer, and steady state flow conditions. Model inputs include spill location, number of contaminant particles, number of stream lines, groundwater velocity, dispersivity, retardation, decay, aquifer thickness and porosity, and well locations, flow rates, and start times (See Figure 9). Model results include duration of simulation, and number of contaminant particles captured, escaped, and decayed. The graphical animation shows contaminant particle tracking, water flow paths, and well locations (See Figure 10). The model incorporates the effects of pumping/injection wells and can be used to evaluate well capture zones as well as pump and treat remediation. Users can very easily "install" wells to capture the pollution, and can evaluate different well locations and pumping rates. This version allows for wells to turn on during the model run, thus changing the flow pattern. Under these flow conditions the model assumes instantaneous equilibrium. File access capabilities enable project information and model parameters to be saved to a file for documentation, or for retrieval and simulation at a later date.

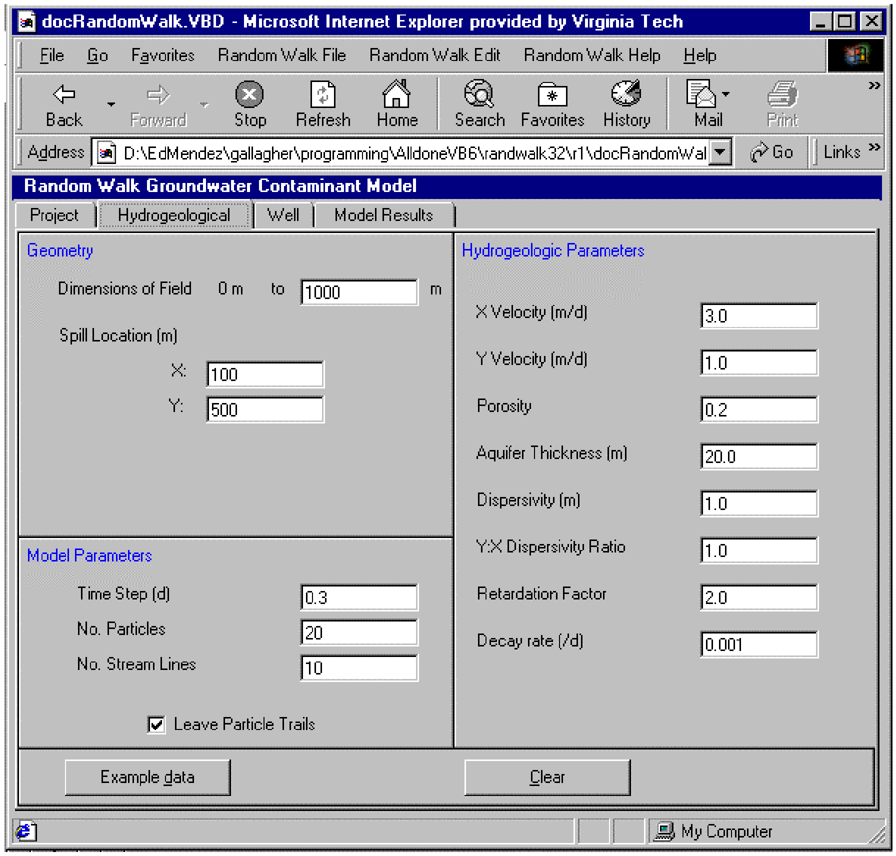

Figure 9. Random Walk Model: Input Screen

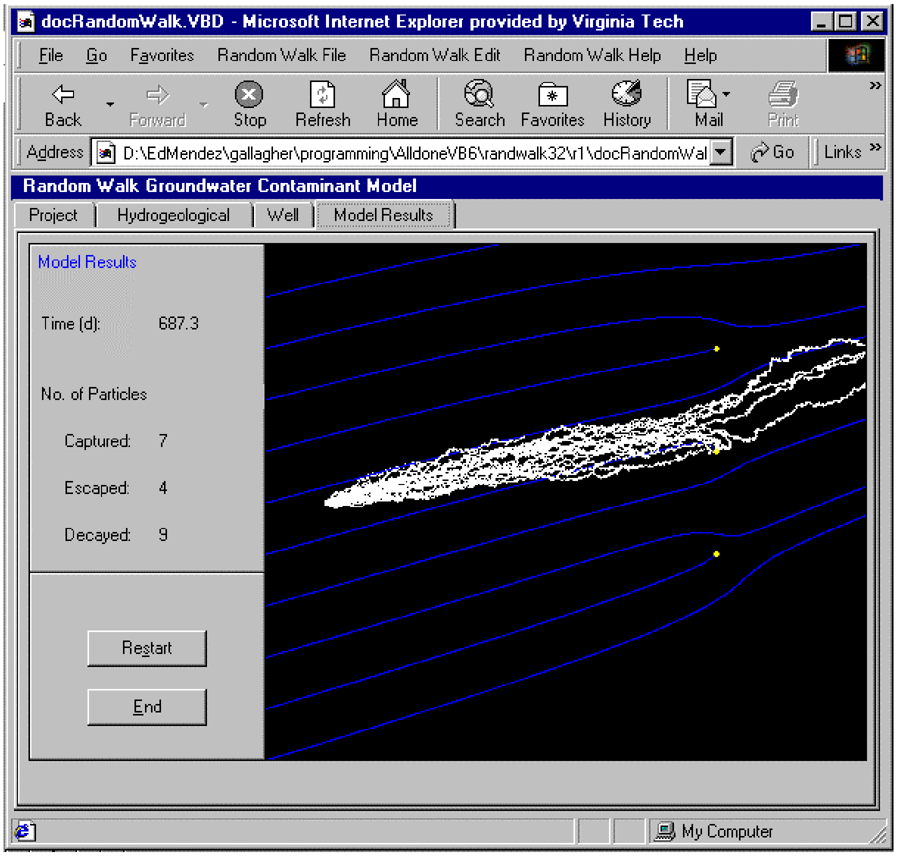

Figure 10. Random Walk Model: Output Screen

Soil Partitioning: This application is a graphical evaluation of a soil fugacity model incorporating contaminant sorption and partitioning among the various soil phases (air, water, organic, and inorganic) (MacKay 1991). Users select a contaminant from a predefined dropdown list or enter data for an unlisted contaminant. The built-in sample data sets allow the quick analysis of sorption parameters. Model input parameters include chemical data such as temperature, molecular weight, solubility, vapor pressure, and reaction coefficients, as well as environmental data such as chemical dosage and leaching rate, soil factors, diffusion distance, and volume and mass fractions (See Figure 11). The user selects the basis for graphing model results using radio buttons (See Figure 12). Users may view graphs of various soil properties for all phases as well as graphs of different representations of chemical distributions among the soil phases. Users may also view reaction graphs for each removal process. Data in tabular format is generated for all chemical and environmental data, soil properties and contaminant distributions, and removal processes. File access capabilities enable model parameters to be saved to a file for documentation, or for retrieval and simulation at a later date. Command buttons enable the displayed graph and tabular data to be printed.

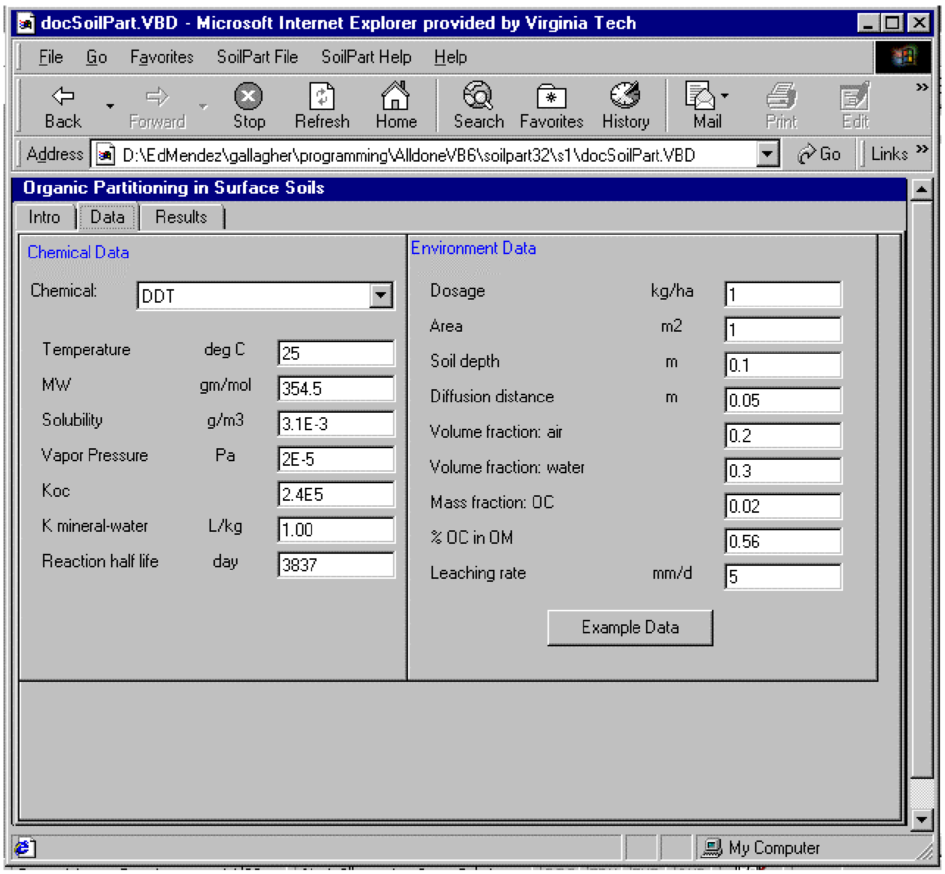

Figure 11. Soil Partitioning Model: Input Screen

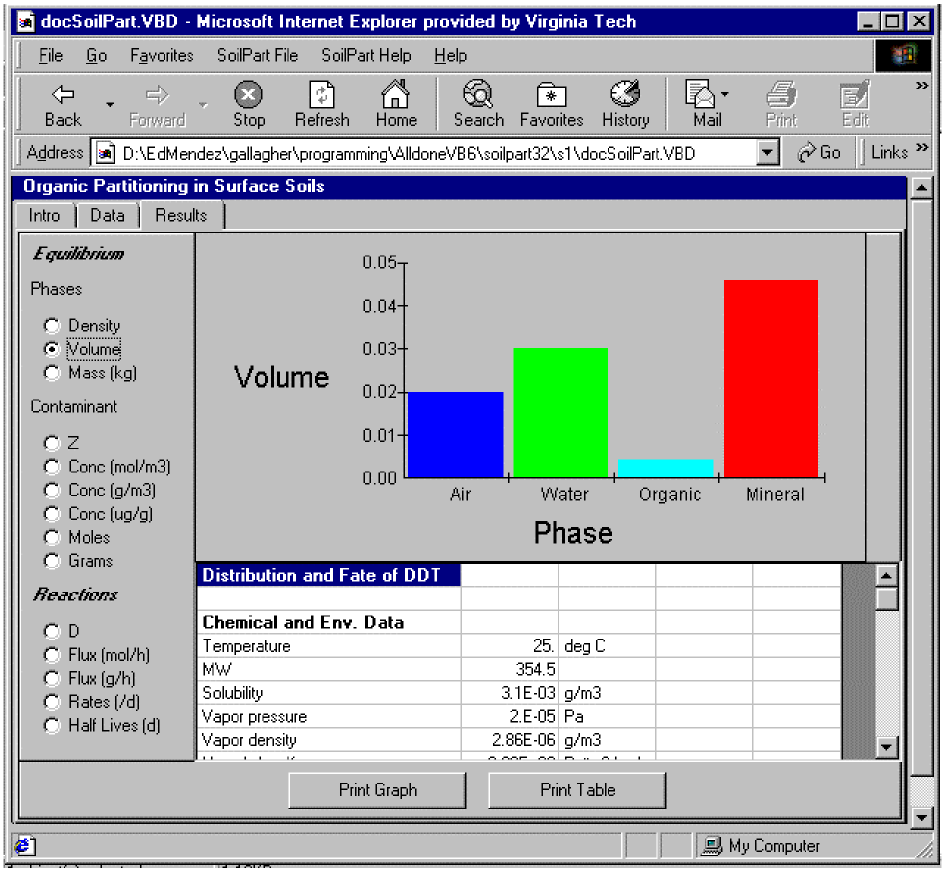

Figure 12. Soil Partitioning Model: Output Screen

Drawdown: The purpose of this program is to graphically illustrate the drawdown of the potentiometric surface in the vicinity of a pumping well (See Figure 13). The model assumes a homogenous, isotropic, confined aquifer, with radial flow to the pumping well. The program estimates the drawdown from the Theis equation and illustrates the development of the cone of depression as a function of either distance at a constant time, or time at a constant distance. The model is useful for explaining critical concepts in well drawdown with inputs including distance or time, flow (pumping rate), transmissivity, and storativity. Students set the values of the input parameters using sliders. Changes to the inputs can be made simply by sliding the appropriate parameter's slider bar up or down. Boxes at the top and bottom of the sliders can be used to set the range for each parameter.

The blue number underneath the slider shows the parameter's value. As the slider moves, the output graph is automatically redrawn. This approach allows for the rapid visual evaluation of a wide variety of options and helps to gain a better understanding of the importance of the model parameters, allowing the sensitivity of the cone of depression to be easily assessed. The graph can be switched from plotting drawdown vs. time to plotting drawdown vs. distance with the click of a button. The scale of the maximum drawdown displayed on the graph may also be varied. The displayed graph can be printed through a menu command.

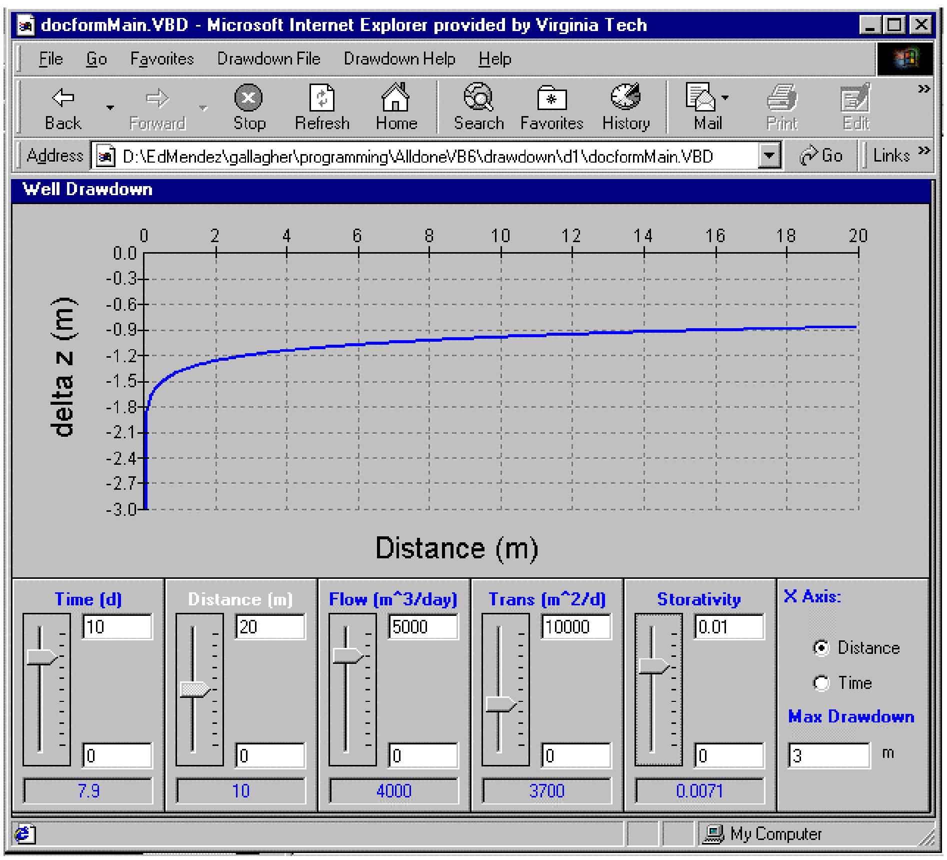

Figure 13. Well Drawdown Model

pCpH Diagrammer: This program can graph the pCpH diagram (See Figure 14) and charge balance (See Figure 15) for a variety of organic and inorganic acids. Model inputs include compound, total concentration of all acid species, metal concentration if any of the acid is added as a metal salt, and charge of the metal ion. The program assumes a temperature of 25 °C, and that the activity coefficients of all species are unity. A predefined acid may be selected from the dropdown box, and the appropriate pKas will automatically be entered. If the acid is not listed, pKas can be entered directly. If used to plot bases, the pKas, not the pKbs, must be entered. The model assumes that if the metal concentration exceeds the total concentration, the additional metal is to be added as metal hydroxide. The charge balance can frequently be used to estimate the equilibrium pH at the intersection of the positive and negative charge curves. Some cases, in which the curves are quite flat and the intersection is difficult to distinguish, the proton condition may need to be applied by hand to find the pH. The charge balance will not be correct for compounds that are + charged at low pH and - charged at high pH. File access capabilities enable input parameters to be saved to a file for documentation, or for retrieval and simulation at a later date. The displayed graph can be printed through a menu command.

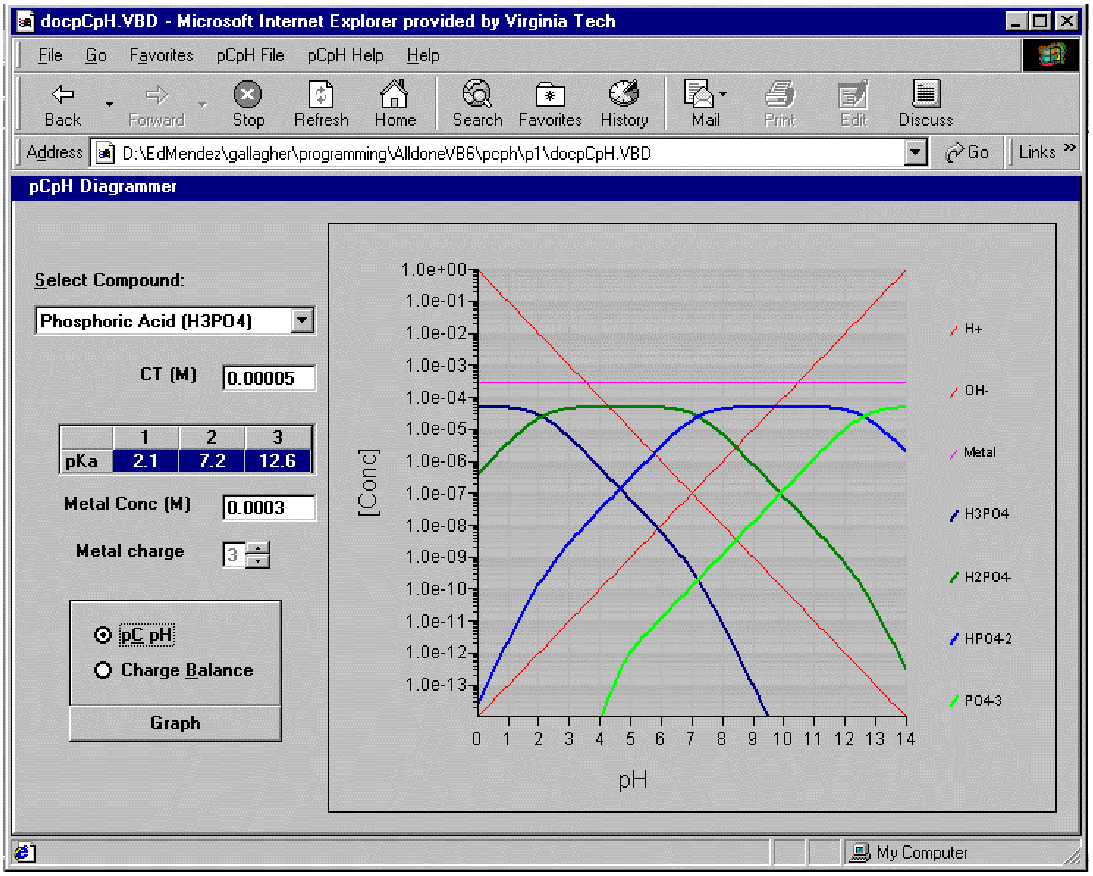

Figure 14. pCpH Diagrammer: pC pH Screen

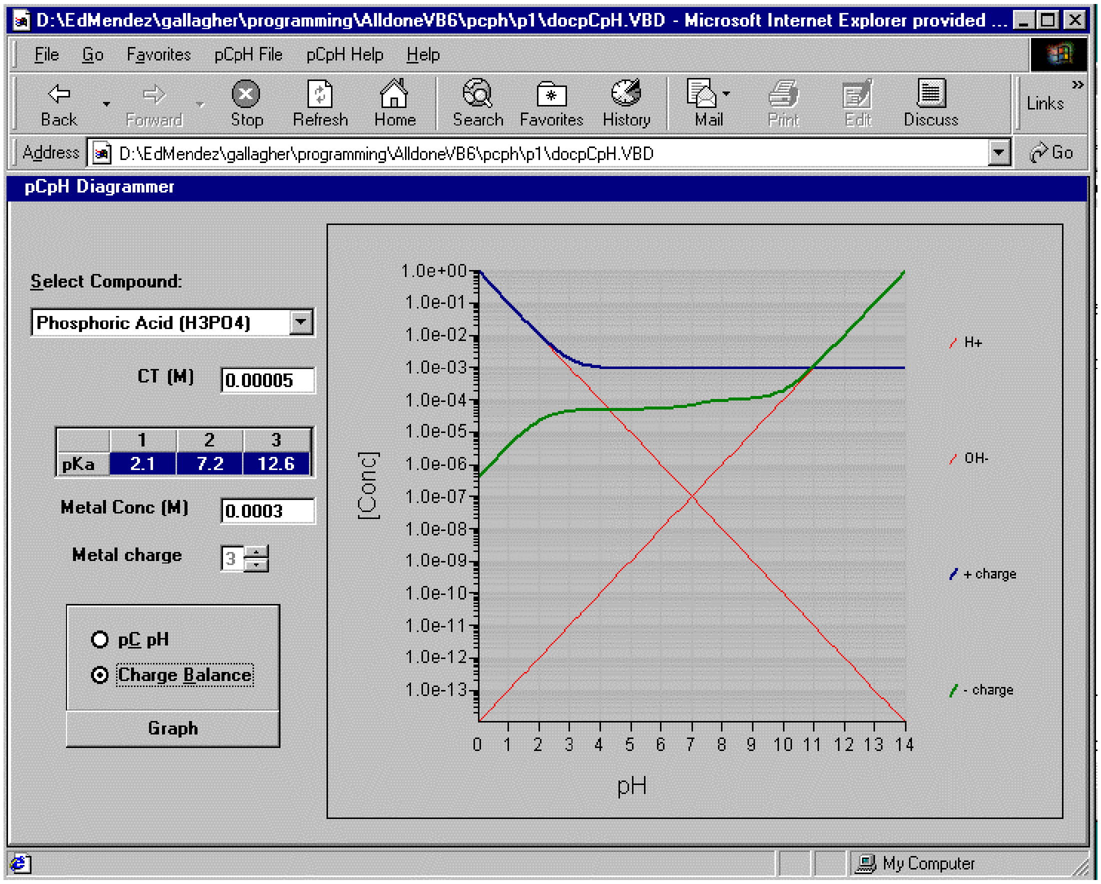

Figure 15. pCpH Diagrammer: Charge Balance Screen

Quizzes

The second approach, the quizzes section, incorporates web-based interactive review and problem solving exercises for groundwater hydrology and contaminant transport. These quizzes are in the form of multiple-choice and short answer questions that provide feedback and guidance through explanations of solution methods and typical errors. Figure 16 shows screen capture of a quiz question. Figure 17 is a screen capture of page that is linked to if question is answered incorrectly (provides additional educational information). There are currently four quizzes; one from each contributing professor of Ground Water Interactive. Additional quizzes will be added as developed. Since the courses involved often emphasize quantitative problem solving skills, this approach will strengthen the skills of the students who are used to more descriptive courses and provide a review of material covered in class. Quizzes were developed with HTML, VBScript, and JavaScript. VBScript, developed by Microsoft, is a subset of the Microsoft Visual Basic programming system. Microsoft Internet Explorer version 3.0 and higher, along with other World Wide Web browsers, can read VBScript programs embedded in HTML pages. JavaScript, a cross-platform, World Wide Web scripting language developed by Netscape Communications, may also be inserted directly into an HTML page. Interactive content is enabled through the use of HTML form elements. Textboxes are used for numerical responses. Validation functions were coded into textboxes to allow appropriate ranges to be entered for each answer. Checkbox elements are provided for Yes / No or True / False statements where an answer doesn't preclude other choices. Radio buttons are used to respond to questions with multiple answers that are mutually exclusive. Submit buttons tells the browser when the student thinks the answer to the question is complete and should be submitted for evaluation. Reset button empties the form inputs and resets any preselected choices to their original values. Command buttons enable the student to link back to previous parts of a quiz question to review information, or to move on to the next question.

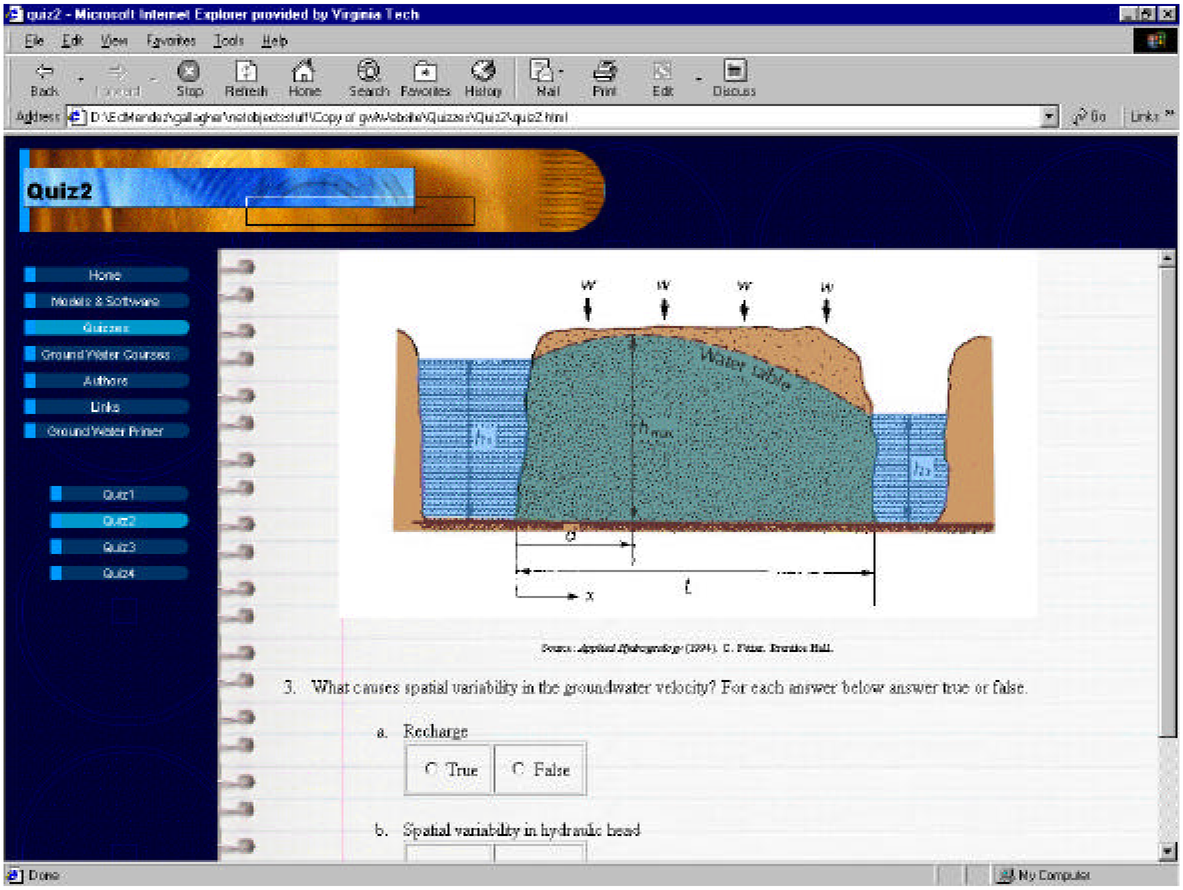

Figure 16. Screen Capture: Quizzes Section

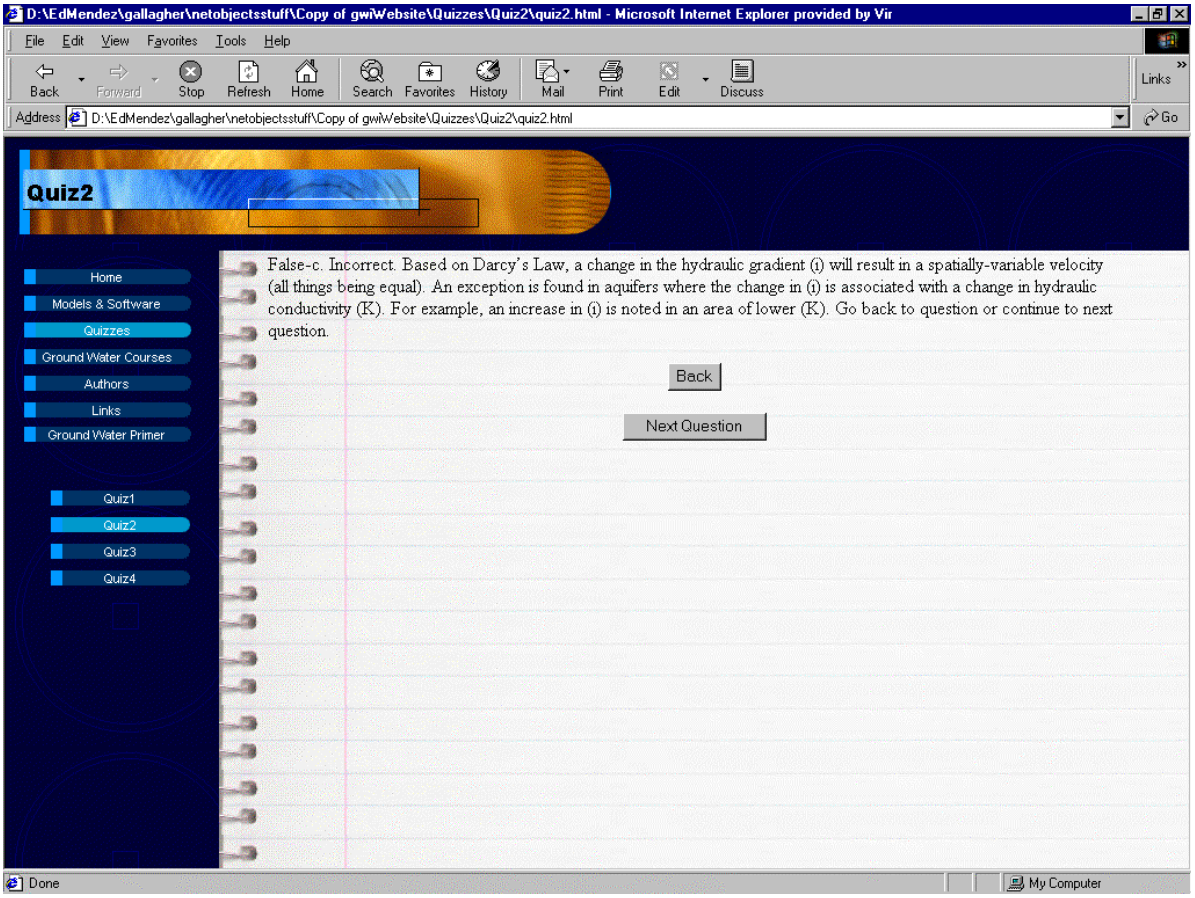

Figure 17. Screen Capture: Quizzes Section Feedback

Primers

The third approach, Ground Water Pollution Primer, is an ongoing project in an interdisciplinary class in the Civil and Environmental Engineering Department and Crop and Soil Environmental Science Department: CEE 4594 / CSES 4594 Soil and Groundwater Pollution. Each term, teams of students are required to write a web page on a topic of their choice dealing with ground water pollution. Webpages are organized and incorporated into the Primer, which is a student-authored, web-based textbook designed to integrate with course material. Figure 18 is a screen capture of one of the student-authored webpages. Primer chapters include; sources of pollution, types of contaminants, transport of contaminants, fate of contaminants, models, remediation, monitoring, and legal aspects. This is a long-term project, in which further topics are added each semester that the class is taught. The primer is designed to provide both deeper learning on a particular topic as well as training in technical writing, web page authoring, and multimedia development. This approach not only benefits the student author, but also other students and the general public, because the primer serves as an additional source of technical information. The most powerful part of the primer as an educational experience is not its use, but rather the students' experience in creating and developing the tool. This is ideal experiential and cooperative learning, as students work together to publish their webpages in a continuing and growing project that adds to the understanding of the material. When students are actively engaged in the design and development of GWI, the extent and the quality of their learning increases as they become more involved and motivated to learn not only the techniques of webpage design but also the content that go into the design (Halpern 1994; Brooks 1997; Tang and Johnson 1999).

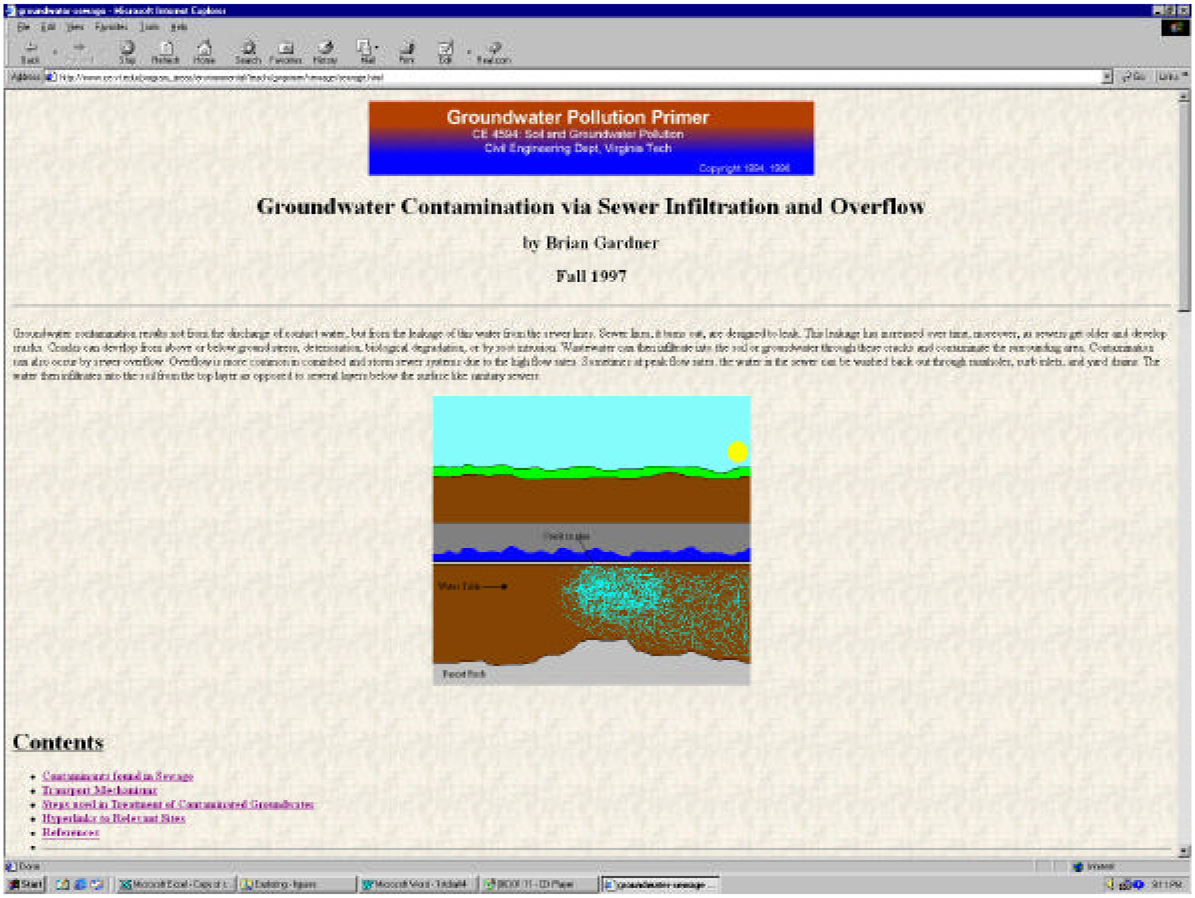

Figure 18. Screen Capture: Primer Section

Enactment of GWI

Implementing GWI

A way to facilitate learning among students with different abilities and learning styles is to incorporate all four of Kolb's learning stages; concrete experience, reflective observation, abstract conceptualization, and active experimentation. "The use of all four stages stimulates students regardless of their learning preferences and challenges them to develop all the skills necessary for effective thinking and problem-solving." (Brock and Cameron 1999). For activities at each learning stage, students with the corresponding learning preference will excel, allowing students to serve as role models for each other, and increasing their self-confidence for learning new material and skills. Through proper structuring of cooperative learning techniques with the GWI tool, all four of Kolb's learning stages will be incorporated and result in higher learning.

Research suggests specific tips to implementing cooperative learning: initially make cooperative learning a small part of the grade; use cooperative learning with criterion referenced grading, as opposed to norm-referenced grading; introduce the technique well; structure the learning activities so that students must learn something, not do something; and provide clarity and organization. Discussing group functionality is essential. Students do not learn from experience what they do not reflect on. "If learning groups are to improve, members must receive feedback, reflect on how their actions may be more effective, and plan to be even more skillful during the next activity." (Johnson et al. 1991; Halpern 1994).

It is therefore recommended to incorporate formal and informal cooperative learning groups into the existing curriculum such that experiential and cooperative learning techniques may be slowly adapted to. Following is a proposed structure for utilizing informal cooperative learning groups for GWI-based in-class activities, and formal cooperative learning groups for primer projects. These two examples are a means of introducing the new learning methodologies and technologies into a more traditional classroom setting, and may be adapted or expanded to other activities or projects, as the teacher deems appropriate.

In-Class

Lecturing with informal cooperative learning groups entails having focused discussions before and after the lecture (bookends), and interspersing pair discussions throughout the lecture. Two important aspects of informal cooperative learning groups are, to make the task and the instructions explicit and precise, and require the groups to produce a specific product. Research on student attention span suggests that breaking up the lecture every 15-20 minutes will result in much higher time-of-task among students. Research also shows that the rehearsal of information soon after its introduction results in greater retention (Halpern 1994). An example procedure follows:

- Introductory focused discussion
- Lecture segment I
- Pair discussion I
    - Formulate
    - Share
    - Listen
    - Create
- Lecture segment II
- Pair discussion II

  Repeat lecture / pair until lecture period is almost over
- Closure focused discussion

This procedure may also be applied in a refined structure for out-of-class activities.

Out-of-Class

The instructor's role in using formal cooperative learning groups includes these parts: specify the objectives for the lesson (academic and social); explain tasks and goals; monitor the effectiveness of the groups and intervene to provide assistance or to increase students' social skills; evaluate achievement and help students discuss how well they collaborated with one another; and evaluate the quality and quantity of their learning (Johnson et al. 1991). Application of formal learning groups for primer projects is as follows:

Students are divided into teams of up to 3 members (Johnson 1994a) and pick a topic with faculty guidance. The students must then write a technical web page that incorporates multimedia (photos, drawings, sounds, animations, videos, etc.). Optional classes are offered to teach the appropriate software and web techniques. The Civil and Environmental Engineering computer laboratory provides all the necessary equipment, hardware, and software to develop multimedia components and student webpages. The use of programming languages and multimedia development introduces students to experiential learning techniques through system design and operation, information handling, and the man-machine interface. The conceptual model for the design project must fulfill three criteria: learnability, functionality, and usability. The projects incorporate aspects of professional practice: topic approval is by means of a 1 page proposal, which enables students to get advice on the suitability of their topic; progress reports are required and draft versions are posted for faculty comment and revision before the final project is due. This feedback mechanism enables students to elaborate on their ideas, and for faculty to make suggestions for improvement. Revision allows for improvement in technical writing skills.

The instructor can also match the difficulty of the project to the ability and experience of the student (Nixon 1993).

Evaluation of GWI

Evaluation and assessment are integral aspects to the incorporation of experiential and cooperative learning, and interactive multimedia as new methodologies and technologies. Two important aspects to the evaluation of experiential and cooperative instructional methodologies are the effectiveness for the student, and the motivational level. Student outcome and motivation can be measured through student feedback, as to the degree to which the course compares to traditional instructional methodologies (Schlager et al. 1999). To assess the usability and instructional effectiveness of GWI, it is recommended both quantitative and qualitative data would be collected at the beginning and end of the semester and analyzed. Data would come from feedback questionnaires (See Appendix A) and grade distributions.

Two sample questionnaires, initial and conclusion, were developed to include both methodological and technological assessment. Surveys contained both quantitative questions (the degree with which a student agrees or disagrees with a statement) and qualitative questions (open-ended questions). Initial surveys, used for a preliminary learner analysis, collect student demographic data, information about past computer use, and prior knowledge of educational methodologies and technologies. Conclusion surveys would assess the student views on the effectiveness of GWI activities and the cooperative environment in helping them learn the material and in making learning more interesting.

This survey is designed to evaluate how students perceived the usefulness of GWI and allows them to express their likes / dislikes about GWI as a whole or how any individual module may be improved.

Class grade distributions would be used to quantitatively evaluate the degree of learning that was achieved. Grades such as from homework, quizzes, exams, and projects, would compare students' performance with those of previous classes. Students' GPAs would also be compared with their final grades to determine the correlation between class and overall performance (Yarbrough and Gilbert 1999). (See Figure 19, Figure 20, and Figure 21)

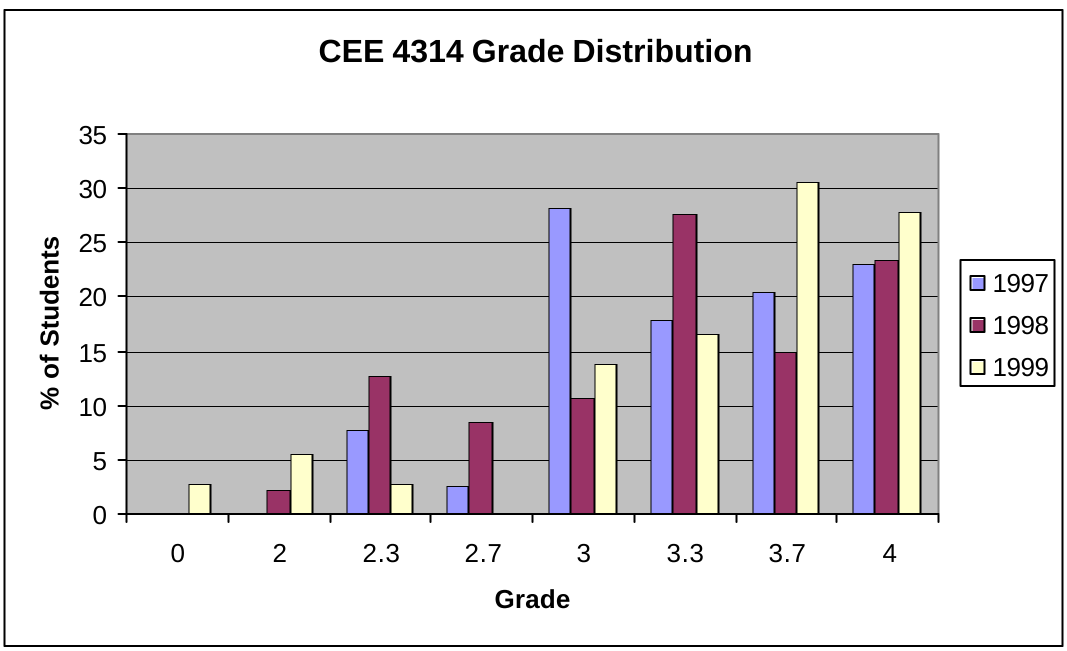

Figure 19. CEE 4314 Grade Distribution

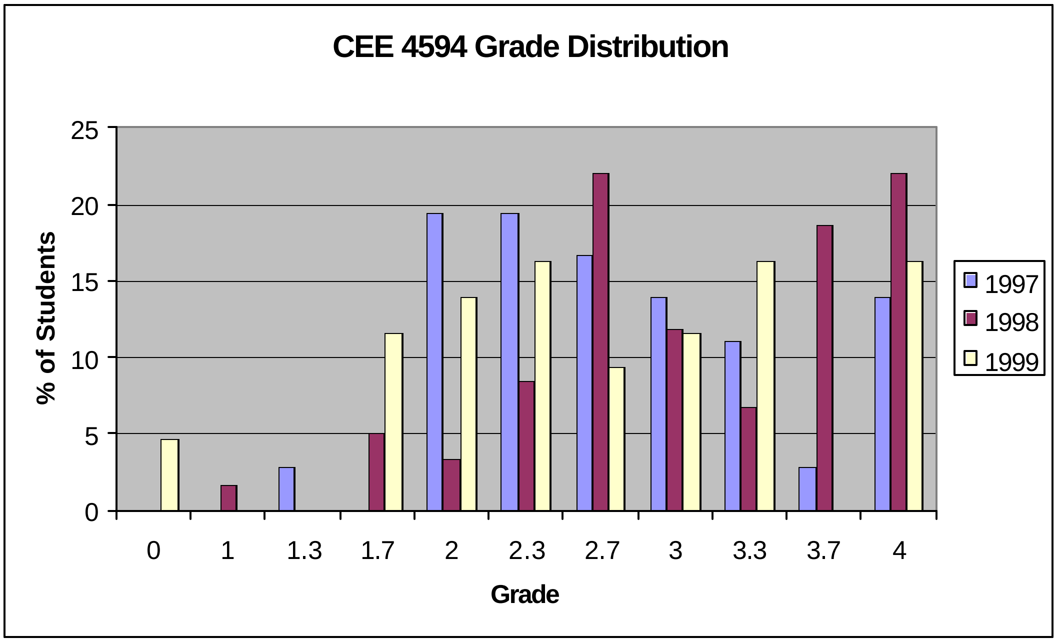

Figure 20. CEE 4594 Grade Distribution

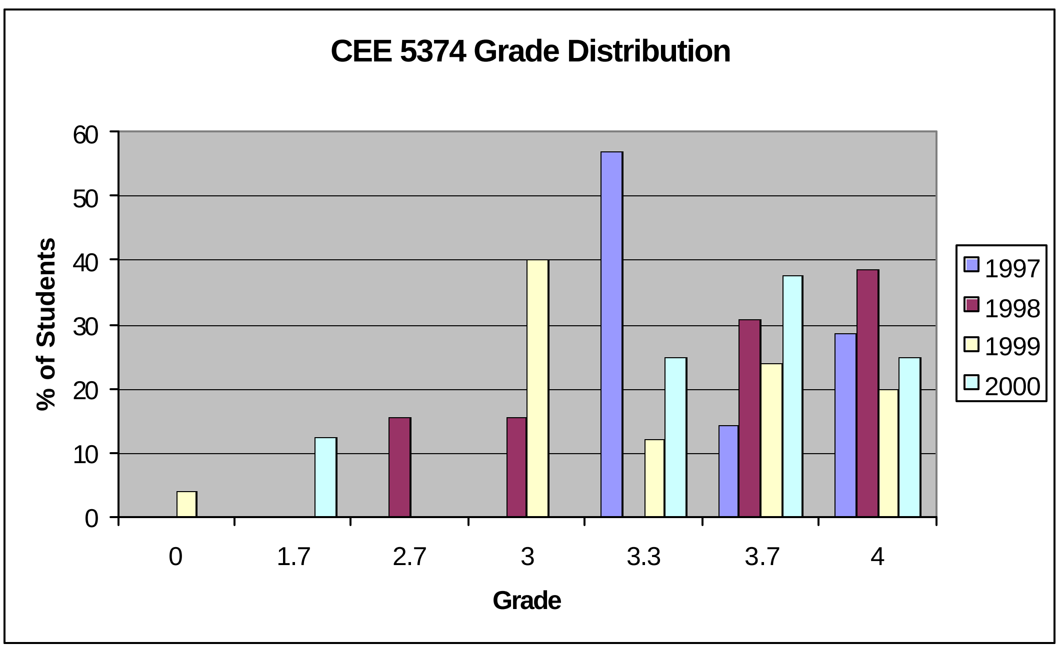

Figure 21. CEE 5374 Grade Distribution

Standard web based statistics should also be collected for GWI, in particular the three main tiers; models, quizzes, and primers sections. These statistics include number of user hits, and the percentage of users from the Virginia Tech community (based on IP address of user). Counts of the number of assignments and the number of student web pages authored would be maintained (See Figure 22).

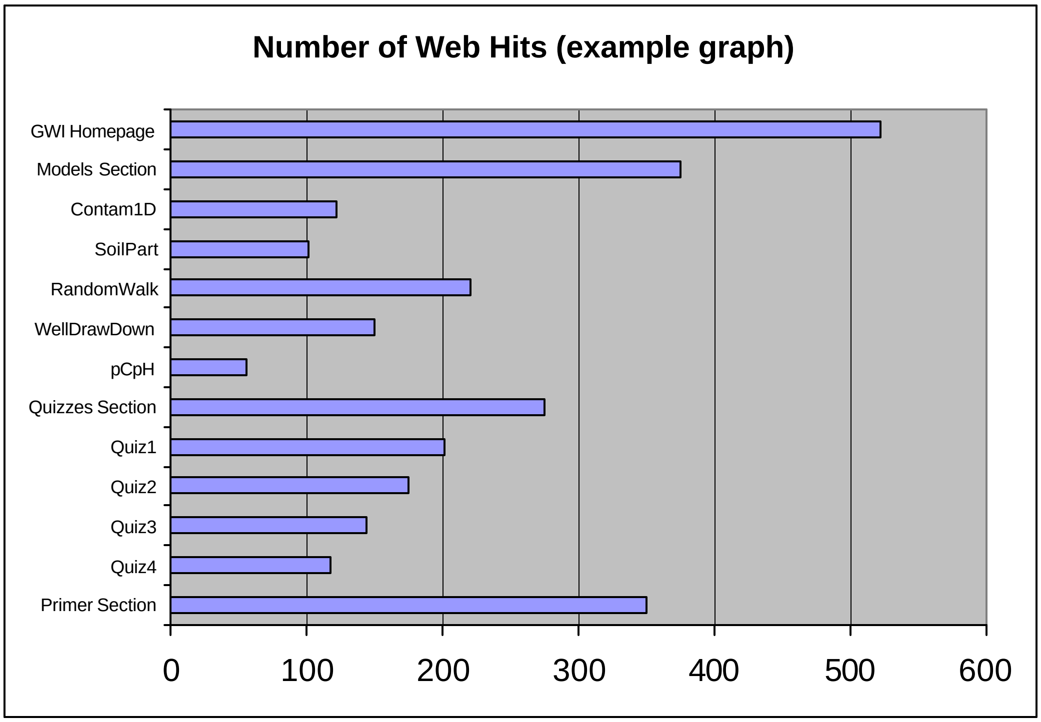

Figure 22. Web Hits

The standardized class evaluation given at the end-of-semester to assess the students' overall perception of the course would also be incorporated (See Appendix B: Standardized Course Evaluations for questions included in the course evaluation).

Continuous Operation and Maintenance

A Graduate Teaching Assistant (GTA) would be required to maintain the GWI site, program or convert, and/or revise interactive models, develop and/or revise problem-based review quizzes, organize and post the student pages, and maintain the evaluation and assessment tools and records. Faculty members would be responsible for overseeing the GTA, for conducting optional classes in web authoring and multimedia development, for continued development of groundwater models and software, for developing suitable questions for the problem review quizzes, for developing homeworks and projects based on the interactive models and quizzes, and for conducting the assessment protocols. Additional GTA/faculty support is required to maintain the web server, for working with students during the web projects, and for addressing general GWI user issues. Continued monetary resources would be needed for hardware and software updates and revisions.

Discussion

Experiential and Cooperative Learning Issues

Often in the application of experiential learning programs, discrepancies appear between theory and practice. As not every experience is valuable, not all experiential learning activities are valuable in their connection to student learning. A criticism is that few faculty members are trained in the 'Principles of Best Practices' to accomplish experiential learning. The 'Principles of Best Practices' include intention, authentication, planning, clarity, orientation, training and mentoring, monitoring and assessment, reflection, continuous improvement, evaluation and acknowledgement. "Experiential education programs will reach their goal of enhancing student learning only when the administration supports a program for training faculty members to participate in it, and when those faculty members can facilitate student comprehension of the meaning of learning through such experiences. Experiential education programs that work are those that are supported by administrators who are committed to programs that facilitate faculty understanding on this learning model and where incentives are given to those teachers who engage in them." (Katula and Threnhauser 1999).

Concerns of instructors about adopting cooperative learning in the classroom include not being able to cover as much content in lectures, not having time to prepare cooperative learning activities, and what happens when some students work and others don't. Considering the use of these teaching methodologies, it is not surprising that some material may have to be omitted to provide time for group member activities. Instructors, therefore, need to access whether such methods are feasible for their course. Also, these teaching methodologies may be more time consuming for the instructor than traditional lecture-oriented teaching. Again, the instructor must weigh the benefits and costs (Johnson 1999).

Another concern with the cooperative learning methodology is that the greater the positive interdependence within a learning group, the greater the chance of disagreement and conflict among group members as they share their different information, perceptions, and conclusions. These controversies can be constructive or destructive, depending on how they are managed and the students' level of interpersonal and small group skills. "When managed constructively, controversy promotes uncertainty about the correctness of one's conclusions, an active search for more information, a reconceptualization of one's knowledge and conclusions, and consequently, greater mastery and retention of the material, and more frequent use of higher-level reasoning strategies." (Johnson et al. 1994b)

Educational Technology and Technical Issues

Identifying promising advanced technologies and planning how to integrate them into instruction are two very different issues. An important finding was that it usually takes years for educational software to be developed and properly implemented (Ehrmann 1995). Reasons for this include under-funded support such that faculty cannot be certain that the required hardware and software will be consistently available and operable, and that it is almost impossible for an unsupported faculty member to find the time and resources necessary for efficient and effective implementation (Ehrmann 1995). The limited teacher support for integrating unfamiliar technologies into education is major concern with the use of technology in schools. As a result, teachers frequently avoid new technologies or use them for purposes other than they were designed for. Changing a course involves shifting to unfamiliar materials, creating new types of assignments, and inventing new ways of assessing student learning. Different instructors, therefore, may respond to technological change in different ways. The challenge they face may cause uneasiness with technological development because it may change personal habits, or the existing culture or power structure (Gerard et al. 1996). Research shows that a large number of faculty members are willing to adopt and implement a technological innovation only if an expert on the subject is available to assist them. Having a specialist available to work with faculty members, and develop new curriculum that incorporates modern technology, should have a high reward in improved learning (Light 1992).

The interactive models are based on Microsoft's new ActiveX Documents technology, which is an extension of their ActiveX Control approach. ActiveX documents run within a container program, in this case the web browser, and appear to the user to be fully web based. ActiveX technology was chosen over the more open Java programming, another technology for creating interactive content. ActiveX components, as opposed to Java applets, register themselves with the operating system so they only need to be downloaded the first time the user accesses the page. ActiveX supports a large number of existing controls, particularly for graphs and spreadsheets, which were not generally available in Java at the time this work was started. ActiveX was also preferred because of its portability from Visual Basic, because of speed concerns for the numerical based models, and because of its file access capabilities. A problem with ActiveX technology is that only some browsers support it. Internet Explorer is currently the only browser that makes wide use of

ActiveX technology (although a plug-in from NCompass Labs, called ScriptActive, allows Netscape Navigator to access ActiveX controls). Another potential downside to ActiveX, is that, unlike Common Gateway Interface (CGI) or Active Server Pages (ASP), the models are actually run on the user's computer, not on the web server. ActiveX components need to be downloaded and permanently installed on the user's machine (using up hard disk space). Some users may have security concerns about this method. The first time you run the model, the download times may be rather long. After that, the model should download very quickly, since only changes are checked. Discrepancies have also been noticed with ActiveX Document not be able to run on some machines. If this is the case, the web-based version of the model may not be run, and the setup package for the stand-alone executable of the model will have to be downloaded instead.

Conclusions

A framework was initiated for improved learning in cross-discipline, groundwater courses, through the development of an interdisciplinary website incorporating new learning methodologies and technologies. A variety of graphical and interactive software models have been developed and are being used as additional educational tools in the groundwater curriculum. Multiple interactive quizzes have been developed by the participating faculty and encompass a broad range of knowledge from across the many groundwater disciplines. Over the past few years, the student-authored websites have grown into a comprehensive primer, not only being a valuable learning experience for the authors, but also serving as a learning resource for other students and the general public. The website, Groundwater Interactive, merges these educational tools together in a format easily accessible by all those involved in the teaching-learning process. GWI serves as the foundation of interactive multimedia available for application of the experiential and cooperative learning techniques discussed in this paper. An assessment strategy to evaluate the effectiveness of these new learning methods and techniques was developed but not implemented as part of this work. To determine the success of GWI as a learning tool, this strategy must be incorporated into the continuous operation and maintenance of GWI. With assessment and instructor-student feedback, the technologies and methodologies used in GWI could then be revised and improved upon in future versions.

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Appendices

Appendix A: Questionnaires

Virginia Tech 1872

Ground Water Interactive Web-Site

Initial Survey

Virginia Polytechnic Institute

and State University

Class: ________________________ **Date:** _______________

When applicable, choose the rating that most accurately reflects your opinion according to a scale of 1 to 5 with 1 being negative and 5 being positive. Please feel free to include comments in the space below each question, and on the back of the pages, if needed.

1. Department :	
2. Major / Program of Study :	
3. Year : junior / senior / masters / doctorate / other: ____________________________	
4. Reason for taking class : required / elective / other: ___________________________	
5. Any previous experience with, or classes related to, this course's material :	yes / no
6. Rate your quantitative problem solving ability :	1 2 3 4 5
7. Rate your knowledge of the sciences (i.e. chemistry, biology, physics) :	1 2 3 4 5
8. Rate your proficiency in computer / software / internet use :	1 2 3 4 5

9. Any previous experience using ground water related computer models : If so, which one(s):	yes / no
10. Rate your technical writing ability :	1 2 3 4 5
11. Have you ever developed web-pages before : If so , rate your ability :	yes / no 1 2 3 4 5
12. What's your experience, if any, in the development of multimedia (i.e. audio, visual, graphical)	
13. Would you be interested in attending optional classes to learn appropriate software and web authoring techniques :	yes / no
14. Do you have the ability to access the internet from home with Microsoft Internet Explorer 4.0+ :	yes / no
15. What is your opinion of using the internet/ computer-based applications as additional learning tools :	

Virginia Tech

Virginia Polytechnic Institute

and State University

Ground Water Interactive Web-Site

Conclusion Survey

Class: ______________________ **Date:** ______________

When applicable, choose the rating that most accurately reflects your opinion according to a scale of 1 to 5 with 1 being negative and 5 being positive. Please feel free to include comments in the space below each question, and on the back of the pages, if needed.

16. Rate your class experience of working with individuals from other departments, majors, and levels :	1 2 3 4 5
17. Rate your quantitative problem solving ability :	1 2 3 4 5
18. Rate your knowledge of the sciences (i.e. chemistry, biology, physics) :	1 2 3 4 5
19. Rate your proficiency in computer / software / internet use :	1 2 3 4 5
20. Rate your web-page authoring ability :	1 2 3 4 5
21. Rate your technical writing ability :	1 2 3 4 5
22. If attended, rate the software and web authoring techniques classes :	1 2 3 4 5

23. Rate the general layout / usability of the Ground Water Interactive site:	1 2 3 4 5
24. Rate the usability of the ground water models :	
Contaminant 1D :	1 2 3 4 5
Soil Partitioning :	1 2 3 4 5
Random Walk :	1 2 3 4 5
Well Drawdown :	1 2 3 4 5
pCpH Diagrammer :	1 2 3 4 5
25. Rate the overall difficulty level of the web quizzes :	
Quiz 1 :	1 2 3 4 5
Quiz 2 :	1 2 3 4 5
Quiz 3 :	1 2 3 4 5
Quiz 4 :	1 2 3 4 5
26. Rate the answer / feedback / guidance format of the web quizzes :	1 2 3 4 5
27. Rate the format of the primers:	1 2 3 4 5
28. Rate the usefulness of these web tools in reviewing background material :	
Quizzes :	1 2 3 4 5
Models :	1 2 3 4 5

Primers : 1 2 3 4 5

29. Rate the usefulness of these web tools in reinforcing / supporting material covered in class :

Quizzes : 1 2 3 4 5

Models : 1 2 3 4 5

Primers : 1 2 3 4 5

30. Rate the usefulness of these web tools for the visualization of groundwater hydrology and contaminant transport processes :

Quizzes : 1 2 3 4 5

Models : 1 2 3 4 5

Primers : 1 2 3 4 5

31. Rate the usefulness of these web tools for interaction with the user :

Quizzes : 1 2 3 4 5

Models : 1 2 3 4 5

Primers : 1 2 3 4 5

32. Which was your favorite model, and why :

33. Which was your favorite web quiz section, and why :
34. Which was your favorite specific primer or primer section, and why :
35. How much time (in hours) do you think you spent using this site :
36. What is your opinion of using the internet/ computer-based applications as additional learning tools :
37. Would you recommend this site to others, outside this class, to use as a groundwater information resource: yes / no
38. Please comment on what you found most positive, most interesting, and most negative with the site and/or how it was administered within the class:

Appendix B: Standardized Course Evaluations

Questions to be included in the Standardized Course Evaluation

- What do you like best about this class
- What do you like least
- Do you think that working on the assigned projects enhances your understanding of the subject matter
- Do you like working with your team
- Are the teams reasonably uniform in terms of ability to do the work
- Does everyone on your team contribute
- Would you prefer to have homework rather than team projects
- Do the projects seem relevant
- Are the lectures interesting
- How can this course be improved
- Would you like to see more courses taught this way
- Other comments (Johnson 1999)

Vita

Eduardo Mendez III was born on November 20, 1972 in Manchester, New Hampshire. He earned his Bachelor of Science degree in Civil Engineering from the University of New Hampshire in 1994. Following completion of the Master of Science degree requirements, he continued studies at Virginia Tech as a Doctorate student in the Hydrosystems Division of the Civil and Environmental Engineering Department.