

# Evaluation of a Prototype GIS Learning System to Teach Civil Engineering Concepts

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**Abstract:** The purpose of this research was to conduct an applied evaluation of a web-based learning system used to teach civil engineering concepts using Geographic Information Systems (GIS). The principal goals of the evaluation were to determine the overall effectiveness of the system and to identify factors that mediated this effectiveness. Students in two sections of a course on geotechnical engineering carried out a lab activity on soil borrow sites during a regular lab session. Those in one section used the learning system, while those in a control section learned about soil borrow sites via a board game designed for the lab. Students completed a quiz over the materials and a subjective questionnaire one week later. Those in the learning system section scored significantly higher on the quiz. In addition, qualitative analyses indicated that students found that the learning system encouraged knowledge integration, motivation, and “real world” application of engineering.

## A Learning System to Integrate GIS into the Civil Engineers Curriculum

GIS is a computerized database management system that provides geographic access (capture, storage, retrieval, analysis and display) to spatial data. While the industry sector of civil engineering has begun the process of integrating GIS within itself, the academic world has been slower to respond. Since civil engineering is replete with uses for GIS functions, public agencies’ (the civil engineer’s primary employer) use of GIS technology is increasing rapidly. There exists a consequent need for civil engineers versed in GIS and able to apply GIS tools to civil engineering problems in innovative ways. The proposed approach is to develop a number of discipline specific modules, similar to the prototype discussed herein, in order to repeat the exposure of this tool to students in the civil engineering curriculum. These modules can be incorporated in existing courses without having to increase the amount of credit hours. The University of Missouri – Rolla was awarded a National Science Foundation Curriculum, Course, and Laboratory Improvement (NSF/CCLI) grant (Award No. DUE-0341016) in order to create and evaluate a prototype of such a learning system. This one-year “proof-of-concept” project was recently concluded with the applied evaluation of the system described in this paper.

The learning system which was developed for the civil engineering curriculum focuses on a geotechnical application. The prototype consists of a comprehensive problem and an associated repository of learning objects organized using a progressive scaffolding (Sullivan et al., 2004) approach (discussed in more detail below). The

system consists of three parts, foundational knowledge in civil engineering, foundational knowledge in GIS (*Arcview*<sup>®</sup> is a popular software application), and an applied problem. The system is designed to be used in classes where students are learning civil engineering concepts and have a first order working knowledge of these concepts. The early application of these concepts is important to enhance learning, very much like a laboratory experience where concepts are taught in lecture and applied in the lab. The students' knowledge of GIS is diverse, since the course where the system is to be used is multidisciplinary with students from various engineering disciplines (e.g., civil engineering, architectural engineering, and geological engineering and geological engineering). This diversity of previous knowledge is an important factor in guiding the system design.

Two important concepts were instrumental in the design of the system. First, information was broken into sharable content objects compliant with ADL/SCORM requirements. Second, a progressive scaffolding approach was used for presenting different types of media. These concepts are discussed in the following sections.

## Learning Objects and SCORM Compliance

The goal of distributed learning networks is to provide a repository of sharable learning objects facilitated by information networks. Conceptually, this means that educators decompose their courses into a collection of fundamental elements, called *learning objects*, and make them available to an information network (Committee, 2002). A learning object is a collection of web displayable material that has an associated learning objective. There are several goals to such a system. For the objects themselves, it is desired that they be *interoperable*, *accessible*, *durable*, and *reusable* (Englebrecht, 2003).

Key to the success of a distributed learning environment is having a common architecture shared across the network to ensure the interoperability and accessibility of the learning objects. In 1999, Executive Order 13111 tasked the Department of Defense (DoD) "to develop common specifications and standards for technology-based learning" (ADL, 2004) resulting in the first draft of the *Sharable Content Object Reference Model* via the DoD's Advanced Distributed Learning Initiative.

The primary user of SCORM-compliant distributed learning networks has been the military. The Army has seen remarkable success with its Distributed Learning System (Chisholm, 2003), with cost savings resulting in millions of dollars. However, university educational information networks have been slow to adopt and utilize these standards (Cheese, 2003). One hindrance is that professors are reluctant to view themselves as "content-providers." Another fundamental difference between military and academic use is that military tends to train whereas professor strive to educate. The GIS project proved to be an excellent translation project because it is a mixture of education and training.

## Progressive Scaffolding

*Progressive scaffolding* is a term we use to refer to a systematic method of providing users with an optimal level of assistance. Within such a system, different levels or tiers of facilitation are provided to match the optimal levels of assistance required. The level could be set by the learner, an instructor, or automatically, based on learner response. We conducted two previous studies which indicated that the approach provides a flexible and viable learning environment. Learners tend to select the most minimal level of assistance first, in order to minimize their interaction with the learning scaffold and maximize their interaction with the fundamental problem to be solved (Hall, Digennaro, Ward, Havens, & Ricca, 2002a; Hall, Stark, Hilgers, & Chang, 2004). This behavior is indicative of the basic principal that the learning system is simply a tool to help facilitate problem solving.

It's important to note that scaffolding, as defined within our framework, refers to guidance that supports the core content, which remains constant across differing levels of scaffolding. Therefore, the degree of scaffolding is not equivalent to difficulty of the content; rather it refers to the degree of supportive context provided. More specifically, in our research the scaffolding dimension has been represented by the media in which the content is embedded: plain text, text with graphics, or video. Thus the scaffolding differs in the degree of abstraction, fidelity, and richness.

## Evaluation Objectives

The primary goals of this evaluation were: a) To determine the overall effectiveness of a prototype Learning System for teaching GIS to Civil Engineering students within the context of a laboratory activity in an undergraduate Geotechnical engineering course; and b) To identify factors that mediated the systems' effectiveness, with a particular emphasis on providing recommendations for development of a complete system.

## Method

### Participants

Fifty-six students enrolled in an undergraduate course "CE 215: Fundamentals of Geotechnical Engineering" at the University of Missouri – Rolla participated in this experiment.

### Materials

Students in the learning system section (see procedure) used the GIS learning system prototype that was developed for this project. The web-based, SCORM compliant system was presented via an experimental version of the Blackboard® Learning Management System, which is SCORM 1.2 compliant. The content is a series of steps for using GIS software (ArcGIS/Arcview) to solve a specific soil borrow site problem. The steps are a set of learning objects. Each step/learning object is referred to as an exercise. The exercise begins with a screen that lists the steps in an exercise, a text version of the activities necessary to carry out the exercise, and a video version, which shows these steps being carried out. The videos were annotated with comments. The only exercise that deviated from this was an interactive soil analysis tool, where students ordered a specific laboratory soil analysis and the results came back to them via email. There were a total of fifty exercises. The web interface consisted of two frames; the left was a navigation frame with the objects represented as collapsible folders and the content was displayed in a second, main, frame (see figure 2). It's important to note that the problem that was used as part of the learning system was not the same problem students were required to complete in the lab, described below. Figure 2 is a screen shot from the learning system.

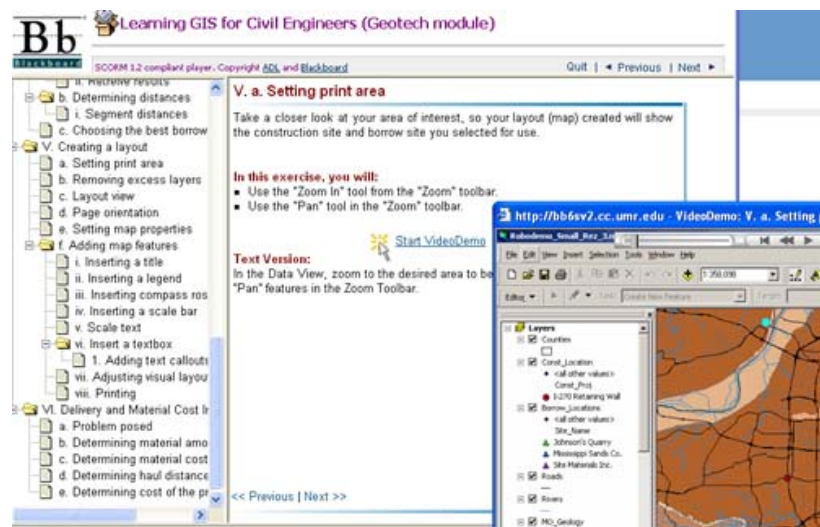


Figure 2. Screen Shot of GIS Learning System

A quiz was used to evaluate student learning. The quiz consisted of twelve items, eight of which were true/false and four of which were multiple choice. The questions covered "Soil Borrow Site Selection" which was the topic of the lab where the applied assessment took place.

Students also completed a post experimental survey. The questionnaire consisted of a series of statements. Students responded to these statements using a 9-point Likert scale ranging from 1 (strongly disagree) to 9 (strongly

agree). These statements were intended to evaluate students' perception of the lab in terms of learning, motivation, and "real world" application. There were also specific items that addressed the text vs. lecture vs. lab components of the course. The items are presented in more detail in the results section. In addition there were two open ended items, which followed the twelve statements, which asked students to comment on the strengths and weaknesses of the lab activity.

## Procedure

The two experimental conditions, learning system (GIS group) vs. traditional lab (control group), were assigned to two different laboratory sections – students in each laboratory section were all in the same experimental condition. Both sections met for two hours on a Wednesday afternoon. Both sections received printed lab directions at the beginning of the lab, which began with a two-paragraph explanation of the concept of soil borrow sites. All students were presented with the goal of selecting the appropriate soil borrow site from a list of possibilities, which met the objectives associated with a given construction site, balancing both the needs and the economic costs. Both sections got the same two objectives, which were: 1) Define what are the engineering objectives and material requirements for a construction earthwork operation; and 2) Select an appropriate soil borrow site for a particular construction site. In addition, the experimental group had a third objective: 3) Use a Geographic Information System for the selection of a borrow site. Those in the experimental group used computers with GIS software (ArcGIS/Arcview) installed and the learning system open in the web browser. Those in the control group used a learning cards/board game, developed for this lab, where the students role played through the procedure of how to examine and analyze geotechnical data to support the borrow site decision. The lab deliverables for both sections included a statement with regard to the site selected, list of lab tests and results, cost, and justification. For the learning system group they were also required to turn in a map developed in the GIS map of the construction and borrow sites with the appropriate data, while those in the control group were required to turn in a description of the anticipated geology or soils for the borrow site, indicating major roadways to get to/from the construction site. In both groups students were divided into two person teams. Each team was given different data for the construction site, and each team was responsible for one set of deliverables.

At the beginning of class two days after the lab, students in both sections completed the quiz over soil borrow sites, and the post experimental questionnaire.

## Results

### Quantitative analyses

The analysis began with a comparison of the learning system and control groups on exam scores and subjective ratings of learning, motivation, and application. This consisted of a series of four two-way between subjects t-tests with condition (learning system vs. control group) as the independent variable in each. Exam scores, learning, motivation, and application rating served of the dependent variables in the four t-tests respectively. The mean scores for the dependent variables as a function of condition with statistically significant results noted are displayed in table 1.

Item	Condition	
	System (GIS)	Control
Exam Score**	81.82%	69.70%
I learned a great deal of information about soil borrow site selection from this week's lab	5.93	6.22
I found this week's lab on soil borrow site selection to be very motivational**	5.17	6.56
This week's lab activity over soil borrow sites was applicable to "real world" engineering.	7.62	7.85

\*\*p < .01 (For ratings, 1 = strongly disagree and 9 = strongly agree)

Table 1: Mean Exam Score and Subjective Rating as a Function of Experimental Condition.

A comparison of pre and post knowledge ratings as a function of experimental condition was carried out by considering students response to an item where they rated their agreement with the statement "Before the lab activity that covered soil borrow sites, I knew a great deal about the subject" vs the equivalent question that began with "After the lab ...". A 2-way analysis of variance was conducted with experimental condition (learning system vs. control) as a between-subject independent variable and perceived knowledge (pre vs. post) as the within-subject independent variable and rating as the dependent variable. A significant main effect was found for perceived

knowledge indicating significant increases in knowledge ratings across both groups  $F(1, 54) = 88.67, p < .001$ . The descriptive statistic, collapsing across groups were ( $M = 3.95, SD = 2.01$ ; and  $M = 6.62, SD = 1.84$ ) for the pre and post ratings respectively.

There were three sets of questions, which asked students to respond to statements about perceived learning, motivation, and application for the lab, course lectures, and the course text. In order to determine the degree to which ratings of the GIS learning system lab compared to ratings of the other course components a series of three one-way within-subject analyses of variance were conducted using only students in the learning system group. In each of these analyses of variance, course component (lab vs. lecture vs. text) served as the independent variable and rating served as the dependent variable. The mean ratings, significance levels, and results of Tukey's post hoc comparisons are presented in Table 2.

item	Course component			Post hoc
	lab	lecture	text	
I learned a great deal of information about soil borrow site selection from ...**	5.93	5.17	4.14	Lab & Lecture > Text
I found ... on soil borrow site selection to be very motivational***	5.17	4.45	3.55	Lab > Lecture & Text
... over soil borrow sites was applicable to "real world" engineering.***	7.62	5.76	4.97	Lab > Lecture & Text

\*\*p < .01, \*\*\*p < .001

Table 2: Rating of learning, motivation, and application items as a function of course component (learning system group only)

## Qualitative Analyses

For students in the GIS learning system group, responses to both of the survey's open ended items were reduced to individual statements. These were then categorized in an effort to identify trends and themes in students' responses. For the item which asked students to identify strengths of the learning system, five themes emerged. For the item, which asked students to suggest ways to improve the system, two themes emerged. It's important to note that there were far more responses to the first question than the second. The themes and a representative comment for each follow:

**Question:** Please list the strengths of the lab activity that covered soil borrow sites, in terms of it's effect on learning and motivation, and it's applicability to "real world" engineering.

**Theme 1** Knowledge Integration: The lab activity encouraged students to understand the content in a holistic fashion, such that they understood the relationships between different content components. ("I had to think about the big picture") **Theme 2** Core Content: The activity facilitated the learning of the core content with respect to soil borrow sites. ("I felt like I learned about the subject.") **Theme 3** Motivation/Engagement: The activity served to motivate and engage students, as compared to normal lab activities. ("... a good break from just seeing theory or doing tests in lab") **Theme 4** "Real World" Application: Students felt that the activity was strongly related to "real world" engineering. ("... very applicable to "real world", shows the types of analysis and calculations needed, shows what kind of decisions need to be made.") **Theme 5** Learning System Usability and Richness: Students found the learning system easy to use and found the videos helpful. ("...the software was easy to use"; "... the videos in the program were very helpful, a lot was learned b/c it was hands on.")

**Question:** Please list ways in which the lab activity that covered soil borrow sites could be improved.

**Theme 1** Additional Guidance/Context: Some students believed that it would be helpful if they were provided with more instructor guidance and/or additional context in terms of the labs meaning and purpose up front. ("... maybe give an intro to what exactly is the goal of the lab.") **Theme 2** Additional Features: Some students requested additional features and information to be provided within the learning system. ("I feel it can be improved with more construction site options ..."; "Include ... negotiating skills.")

## Conclusions

With respect to the first objective of the evaluation, the overall effectiveness of the GIS learning system appeared to be very good. First, those who used the learning system in the lab scored significantly higher on the quiz over the lab content. This was further supported by the qualitative results, in that many students indicated that the

lab enhanced the learning of core content; while emphasizing knowledge of the relationship among the concepts associated with soil borrow sites. This was presumably supported by the fact that students found the lab activity, which included the learning system, to be strongly related to what they perceived to be “real world” engineering.

Despite the strength of the lab, which included the GIS software and supporting learning system, it’s interesting to note that those in the control group had a significantly higher rating for the item pertaining to their motivation during the lab. Therefore there was an incongruity between the objective measure of learning, where the learning system group scored significantly higher, and their ratings of motivation during the lab, where the control group scored significantly higher. There are a number of possible explanations for this counterintuitive finding. First, in the control activity students learned about borrow sites by playing a cards/board game and the notion of playing a game may have simply been more enjoyable and motivational for the students in comparison to the learning system group where they carried out a step by step activity of selecting a borrow site. It’s also important to note that those in the learning system group did not find the activity as detrimental with respect to motivation. Their mean rating of motivation was above the mid point (5.17 on a scale of 9). In addition, their responses to the open ended questions indicated that, over-all they found the activity motivational and engaging.

The second goal of the evaluation was to identify factors that mediated the effectiveness of the learning system. First, it appears that the over-all design of the system is effective, so changes to the system should be made with caution. As for students’ suggestions for improvement, some indicated that additional guidance and context should be provided. Additional guidance could be partly a function of how the system is integrated into a course, in that the course could be designed such that more information is provided before the system and associated activities are introduced. In addition, a more elaborate introduction could be added within the learning system itself. Students also suggested additional features, in the form of more options and additional components, such as instruction in negotiation. These types of features can be added sequentially as the final system is developed in such a way as it does not interfere with the basic system design.

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