Integration of a GIS Learning Management System into Civil Engineering Curricula: An Evaluation

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Abstract: An evaluation of a web-based e-learning system to facilitate integration of Geographical Information Systems (GIS) into the Civil Engineering curriculum was conducted. The principal goals of the evaluation were to determine the overall effectiveness of the system and the factors that mediated its effectiveness. Data were collected from 80 students who participated in a regular geotechnical computer laboratory session, which covered soil borrow sites. Students rated the laboratory session as significantly more effective for learning, and more motivational than the class texts. They also rated the lab significantly more applicable to real world learning than both their text books and class lecture. Furthermore, students rated their knowledge about the subject area significantly higher after the laboratory session than before. Qualitative analysis identified holistic learning, real world applicability, engagement, clarity, and motivation to be the prime factors in mediating the effectiveness of the learning environment.

Introduction

Geographic (or Geographical) Information Systems (GIS) have been defined in many ways by many people. Environmental Systems Research Institute (ESRI), an industry leader in GIS software and geo-database management application defines GIS as, “An organized collection of computer hardware, software, geographic data, and personnel designed to effectively capture, store, update, manipulate, analyze, and display all forms of geographically referenced information” (ESRI, 2008). Star and Estes (1990) defined GIS as, “A system that is designed to work with data referenced by spatial or geographic coordinates. In other words, GIS is both a database system with specific capabilities for spatially referenced data, as well as a set of operations for working with data. In a sense, GIS may be thought of as a higher-order map". We could call these "data driven maps". In addition, Maguire (1991) identified two perspectives for describing GIS, the technological and organizational perspective.

Initially developed by government agencies and later by private industry to store, organize, and analyze data that can be described or modeled spatially or geographically (Black, MacDonald, & Black, 1998), GIS is now being utilized in various disciplines. In recent times, the use of Geographical Information Systems (GIS) has become popular (Francica, 2000; Lubenow & Tolson, 2001; Hockstra & Mattejat, 2002). From decision support for various industries to develop and implement policy at the federal, state, and local levels, GIS has been extensively used. Civil engineering projects involve the management, analysis, and integration of very large amounts of spatially distributed geographic information to ensure success. In sharp contrast to the proliferation of GIS implementation in the industry sector, academia has been slow to respond to these advancements. Integrating GIS concepts into civil engineering education is not only important to meet the urgent needs of non-GIS professionals in engineering, but also to teach students relevant skills in spatial analysis, reasoning and data processing (Easa et. al., 1998). Furthermore, implementing GIS into the curriculum may encourage students to examine data from a variety of disciplines (Furner and Ramirez, 1999; Sarnoff, 2000).

The learning system consists of a comprehensive problem and an associated repository of learning objects organized using a technique we refer to as progressive scaffolding (Hall, Watkins, & Eller, 2003; Hall, Digennaro, Ward, Havens, & Ricca, 2002; Hall, Stark, Hilgers, & Chang, 2004; Sullivan et. al. 2005). In progressive scaffolding, students are provided with different levels or tiers of facilitation to match the optimal level of assistance. The overall objective of this project is to develop a number of discipline specific learning modules in geotechnical, transportation, water resources, surveying, and environmental engineering in order to expose this tool to students in civil engineering without increasing the number of courses or credit hours.

The goal of this research was to evaluate the effectiveness of the prototype module, which covers geotechnical engineering, to identify factors that mediate this effectiveness, and to develop a preliminary model to describe the processes associated with students interacting with the system. In order to address these goals, both quantitative and qualitative methods were used.

Learning Objects

The learning system in this project is comprised of sharable learning objects. In simple terms, Wiley (2001) describes learning objects as any digital resources that can be reused to support learning. Educators decompose their courses into a collection of fundamental elements known as learning objects and make them available to an information network (IEEE, 2002). In this context, the reusable learning objects can also be defined as an independent and self-standing unit of learning content that is predisposed to reuse in multiple instructional contexts (Polsani, 2003). The desired characteristics of the learning objects are that they be interoperable, accessible, durable and reusable (Englebrecht, 2003).

For the learning objects to maintain their characteristics and have a common architecture at the same time, the Department of Defense was tasked to develop common specifications and standards for technology-based learning (ADL, 2008). The Sharable Courseware Objects Reference Model (SCORM) was the result of that initiative which is basically a collection of guidelines, recommendations and standards for the creation of web-based learning-object systems. These standards ensure that the learning objects are interoperable, accessible, reusable and sharable.

Even though the Military has seen remarkable success with the distributed learning system (Chisholm, 2003), university educational information networks have been slow to adopt and utilize these changes (Cheese, 2003). The hindrance is that the professors are reluctant to view themselves as "content providers" (Hall et al., 2005. Another fundamental difference between military and academic use is that military tends to train whereas professors strive to educate (Hall et al., 2005). This GIS project is the culmination of different fields of engineering and a mixture of both education and training. Therefore, the system was developed in accordance with SCORM standards and its continued use is being evaluated for the future modules.

Progressive Scaffolding

Different levels of assistance are provided to the students in the learning system. Students can choose from either a text version or a detailed video version of the task to match the optimum level of assistance they require. “Progressive scaffolding” is the term we used to refer to this type of systematic method of providing learners with an optimum level of assistance (Hall, Watkins & Eller, 2003). The learning system is designed in accordance with the progressive scaffolding approach, in which the supporting materials are offered in a progressive fashion from the most general and minimum guidance (text) to the most specific and detailed (video) (Fig. 1).

In the learning system, at the core of each module is a problem, which requires the learner to actively integrate knowledge from multiple sources and apply basic methods and procedures for its solution. Therefore, the degree of scaffolding is not concerned with the difficulty of the content, but refers to the degree of supportive context provided i.e. plain text or video. In previous research, three levels of scaffolding were used in a similar system; text, graphics, and video. The results indicated that the participants largely ignored static graphics (Hall et al., 2003). As a result, only two levels of abstractions were provided to the participants in the Geotech/GIS system.

Method

Participants

The participants for this research were freshman students enrolled for an undergraduate course “CE 215: Fundamentals of Geotechnical Engineering” at Missouri S&T.

Materials

The participants for this research were asked to use the GIS learning system developed to solve specific problem related to soil borrow site selection. The web based learning system consists of a series of steps to support students in using commercial GIS software (ArcGIS/ArcMap), where each step or exercise can be considered a learning object. The system also provides the context for the use of ArcGIS/ArcMap by including a specific problem to be solved, in this case, soil borrow sites. The web interface listed information in two columns (Fig. 1).

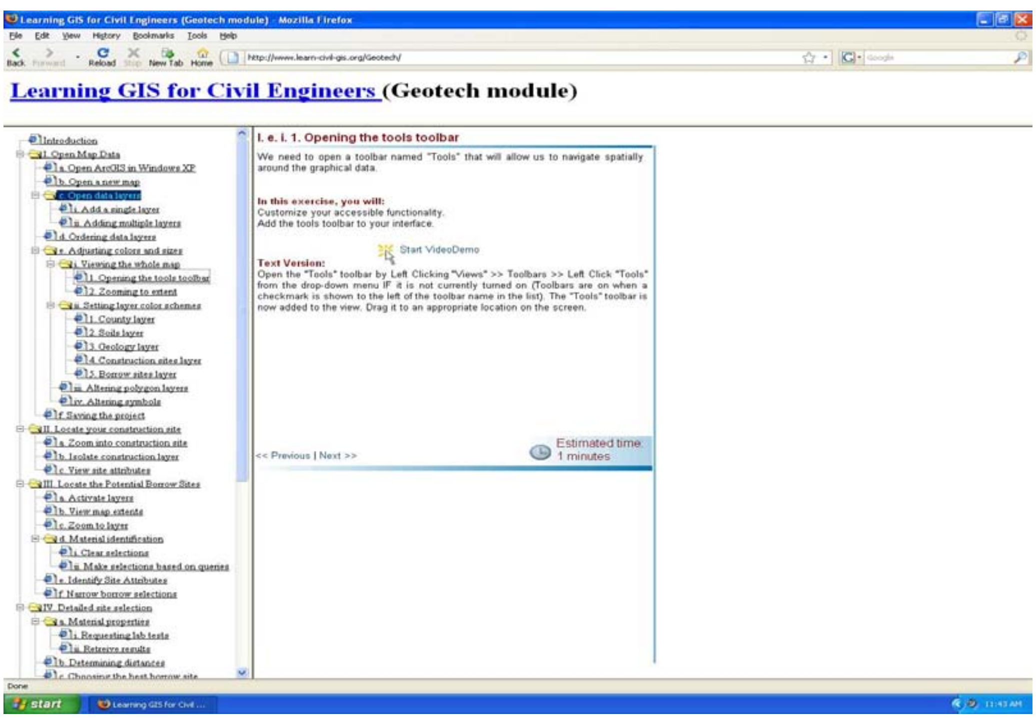

Figure 1: Screen shot of GIS Learning System

There are 47 instruction pages pertaining to solving soil borrow site selection problems as well as problems related to translating ArcGIS data into useful information. The left column consisted of collapsible navigation components whereas the right column consisted of contents for each item that was selected in the left column. Consistent with the progressive scaffolding approach, the contents in the right column consisted of a text version of the activities necessary to carry out the exercise as well as the link for the video version. One of the exercises consisted of going to a virtual soil analysis webpage which would send the results for the requested soil test in the email address provided by the participant.

A day after completing the lab excercise, students filled out a questionnaire. The questionnaire included a series of 9-point likert-scale questions ranging from 1 (strongly disagree) to 9 (strongly agree), each followed by an open-ended question. The likert-scale questions were intended to evaluate student's perception of the laboratory activity in terms of learning, motivation and real world application, relative to other class components (text & lecture). A quiz was used to evaluate student learning during the lab session and the questions were related to soil borrow site selection. In addition to the likert-scale questions along with its subsequent open-ended questions, there were two specific open-ended questions pertaining to strength and weakness of the laboratory activity.

Procedure

Students from the "Fundamentals of Geotechnical Engineering" course consisted of six different lab groups. Each lab session was 2 hours long and two lab sessions were carried out each day from Monday through Wednesday. In the labs covered in this evaluation, the students were provided with a concept of soil borrow sites along with printed lab directions before the start of the laboratory session. The objectives of the laboratory session were to: 1) Define what are the engineering objectives and material requirements for a construction earthwork operation; 2) Select the appropriate borrow sites for a particular construction site; and 3) Use a Geographic Information System for the selection of a borrow site and preliminary cost estimate. Students used computers with preinstalled GIS software (ArcGIS/ArcMap) along with the learning system open in the web browser. Students were then asked to fill out the consent form along with the computer number they used. The students had to download a data set from the learning system's website and then proceed to the tasks at hand. The lab deliverables included a formal memo describing the reason for the selection of the site, results from the soil test, materials and delivery costs as well as the GIS map of the construction and borrow site along with appropriate data.

Students were allowed to pair up in a group of two if they preferred. The students had the option to submit the deliverables at the end of the lab session or submit it in class the next day. A day after finishing all the laboratory sessions, students were asked to fill out the questionnaire and to complete a quiz that consisted of a series of technical questions related to soil borrow site selection.

Results

Quantitative Analyses

Three sets of questions pertaining to perceived learning, motivation and real world application were asked in the questionnaire. In each set, students were asked to rate class lecture, class text, and the learning system. A series of three one-way within-subject analyses of variance were performed in order to compare the GIS learning system laboratory with class lecture and text. In each of the analyses of variance, course component (lab vs. lecture vs. text) served as an independent variable and rating as the dependent variable. All three analyses of variance were significant at $p < .001$ level. The significance along with mean ratings and Tukey's post hoc comparison are presented in Table 1.

	Lab	*Lecture*	*Text*	*Post Hoc*
*I learned a great deal of information about soil borrow site selection from …**	5.600	5.138	4.250	Lab, Lecture > Text
*I found ... on soil borrow site selection to be very motivational**	4.650	4.275	3.638	Lab, Lecture > Text
*… over soil borrow sites was applicable to "real world" engineering**	7.588	6.125	5.112	Lab > Lecture > Text

* $p < .05$

Table 1: Scoring of learning, motivation and real world application as a function of course components

In the questionnaire, students also had to rate their knowledge level before and after the laboratory activity ("Before the lab activity that covered soil borrow sites, I knew a great deal about the subject area" vs. "After the lab activity that covered soil borrow sites, I knew a great deal about the subject area"). A one-way analyses repeated-measures analysis of variance was conducted with perceived knowledge (pre vs. post) as the within subject independent variable and rating as the dependent variable. The results indicated that students rated their knowledge after the lab (Mean = 6.63) significantly higher than before (Mean = 4.54) ($p < .05$).

Qualitative Analyses

Sample and Data Collection

There were thirteen Likert items where students could explain their answer, and the two open-ended questions asked students to list the strengths of the lab activity and the ways in which the lab activity could be improved. In addition to the open ended responses on the questionnaires, researchers observed and collected field notes during the laboratory sessions. Students' open-ended responses on the questionnaires and the field notes constituted the data for the qualitative analysis.

Results

Students highlighted a number of factors that determined how they felt about the learning system, what they wanted from it and what they gained from their experience. Two themes immerged: *1) Learning Environment Properties* and *2) Outcomes.*

1) Learning Environment Properties

Students mentioned holistic learning, real world applicability, engagement, clarity and motivation to be the prime characteristics for a good learning environment. Students want to have control over whatever they are doing, as opposed to just following steps. They want to understand the big picture of why they are doing what they are doing. For example, one student commented, "*We had to explore on our own to come up with the answer not just following the steps and that is what I like*". With respect to their preference for holistic learning, one student said, "*Doing something like this (lab activity) in the lab makes me understand the big picture and makes it more clear to me why I am doing certain things*".

Real world applicability is another factor that students stressed. Students want to go beyond the traditional task solving techniques in which instructors provide problems and students solve those problems by any means necessary. They want the tasks to be challenging; while, at the same time practical to such an extent that they can relate it to the "real world". One of the students mentioned, "*We try solving so many problems in class that we generally don't have to go through when we go out and work. It (lab) accurately uses a real world situation to solve problems and that is what interests me*". In other words, students want to have hands-on learning about things that they might be doing when they go out and work. As far as the real world relevance is concerned, one of the other students commented, "*It was like what you would do in the real world. The tutorial helped me learn by breaking down each step and making it understandable why each step was important and it was motivational because it was something I could see myself enjoying more so than book problems*".

Students also stressed the importance of tasks being engaging. With the addition of real world data, students feel much more engaged in solving the problems. The laboratory deliverable consisted of selecting a soil borrow site for the construction sites and one of them was Downtown St. Louis Stadium. It was easy for the students to relate to the existing problem with the real data and in return being engaged and motivated. For example, "*Real data and information helps me be focused*". Another student mentioned, "*Using places that are relatively known and having to make the engineering decision based on cost and effectiveness was intriguing to the topic*". According to one of the other students, "*I felt really focused while doing it because this problem stands out from the rest of the problems we're used to solving*".

During students learning, clarity is another important factor. Even though detailed information is not required at all times, students feel that sufficient explanation is required for important tasks. In solving laboratory tasks, they would have liked a little more detailed information about the borrow site selection and mining information from the soil test results. One of them mentioned, "*If some additional information were given to us before the lab about how to pick the borrow sit. It would have been helpful*".

Motivation was another factor that emerged as essential for an effective learning environment. The problems in the laboratory sessions were considered motivational by the students because it represented something they would have to do when they go out and work. One student stated, "*I found the lab to be extremely motivating because of its direct relation to 'real world' engineering and I might be doing this someday. I would like to pursue this further*".

2) Outcomes

The outcomes from the laboratory activity were further divided into experience outcomes and knowledge outcomes. The experience outcomes being 'better hands on learning', 'improved exploratory skills', 'enhanced learning' and 'improved learning'. After completing the laboratory session, students acknowledge the importance of the laboratory tasks because that would be something they would have to do when they graduate. With the real geographic data to explore and navigate, students felt motivated and they acknowledge learning something from the laboratory activity. As one mentioned, "*This is as hands-on learning as it can get before you go out and work*". The laboratory activity is created in such a way that students have to use their own engineering logic rather that just following steps. Therefore, they mentioned having improved exploratory skills after the laboratory activity. One of the students mentioned, *"(Lab) made the process very simple. Seemed like a program you would use in the future – motivational to me because it's not just punching numbers. It's that and using your engineering logic*".

The knowledge outcomes are 'better integration of different subjects', 'better visual understanding', 'understanding of cost considerations', 'understanding of site/soil considerations', and 'understanding of software program'. As students have to use their own reasoning and facts, after the laboratory activity, students mentioned having better knowledge integration of different subjects. One of them mentioned, "*Very good activity. Incorporated costs (real world), GIS program and prioritizing (soil integrity vs. cost)*". With the GIS program, one crucial factor is added to students understanding and that is better visualization. One of the students commented, "*The detail of the maps including roads was helpful in visualizing how an engineer should decide which borrow site to pick with all variables considered*". The laboratory activity involves selecting a soil borrow site from among other sites considering soil composition, cost and transportation cost. Therefore, students mentioned having better understanding of transportation cost considerations and site/soil considerations. As one of the students commented, "*It taught a lot of the transportation costs via map. It also helped figure the pricing for the soil. It also taught the benefits of different sites*". Another mentioned, "*It showed that there are several factors in determining borrow site other than just the soil type*". Similarly, one of them mentioned, "*I learned how to compare 2 different ones and choose the best; I learned what makes one better than the other*". Apart from experience outcomes and specific subjective understanding, students mentioned having a better understanding of the GIS software used. The majority of students had little to no previous experience with the GIS software. One of the students commented about his experience with the GIS software as, "*I didn't know GIS could do all of that! It looks like an amazing program!"*

Figure 2 represents a basic model for student learning of the GIS learning system. This research introduced a learning module within the laboratory setting but in essence, it is a stand-alone laboratory component i.e. students can learn about the different modules (Geotechnical, Surveying, Transportation, Water Resources, and Environmental) as they would normally in a laboratory, lecture and from the text book. Therefore, the learning system is taken as a separate learning technique.

In this research context, prior knowledge and future discipline of interest are considered as moderators since varying level of these affects the level of outcome. Students with prior experience (internships/job) resulted having experience and knowledge outcomes to a lesser degree than students with no prior experience. One of the students mentioned, "*I did a lot of this last summer at my internship, didn't really taught me anything new*". Future discipline of interest was another moderator that varied the outcome. For those students who had already selected a discipline (Surveying, Transportation, Water Resources, Environmental etc.) or those who have already made up their mind in any civil engineering field other than geotechnical, it was less engaging and motivating for them. One student commented, "*I liked the lab. It was fairly easy to understand. I think the program would be very useful if I was interested in geo-tech engineering*". Another student mentioned, "*I don't want to work in geotechnical engineering. So, I really don't care*".

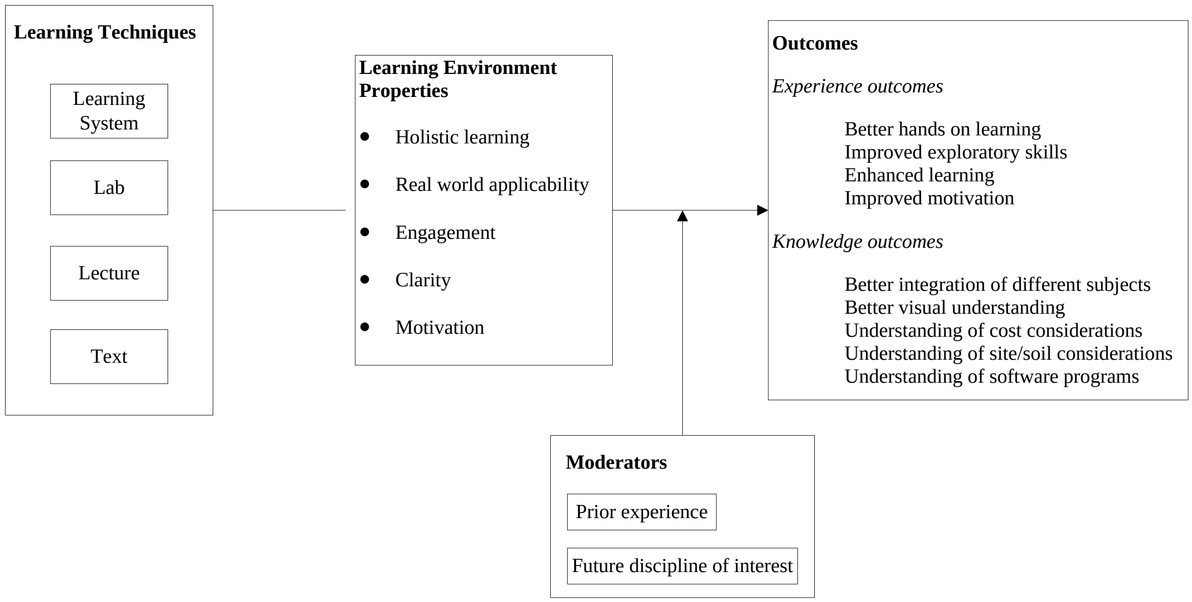

Figure 2: A model for students learning of the 'GIS learning system'.

Kerski (2003) identified several perceived benefits of GIS implementation in secondary education including 1) Providing real world relevance, 2) providing exploratory skill, and 3) Enhanced learning and motivation which is consistent with the results of this qualitative analysis.

Conclusions

In regard to the first objective of this research, both the quantitative and qualitative analysis supported the effectiveness of the system. The statistical analysis indicated that students rated the laboratory as significantly more effective for learning and motivation in comparison to their textbook. In addition, students rated the laboratory significantly more applicable to real world learning than their class lectures or the text. Furthermore, students rated their knowledge about the subject area significantly higher after the lab than before. Qualitative analysis corroborated the quantitative finding in that the results indicated that the laboratory activity indeed enhanced the learning of core content along with improved motivation and its relationship to real world engineering.

The second goal of this research was to identify the factors that mediated the effectiveness of the learning system. Qualitative analysis identified holistic learning, real world applicability, engagement, clarity, and motivation to be crucial in students learning environment. For the learning system to be effective, the above mentioned factors should be taken into consideration. Students' comments suggest that the overall design of the learning system is effective.

The basis for qualitative data was primarily the unstructured open-ended questions from the questionnaire and the field notes. Therefore, interviews will be carried out in the next laboratory session to further refine the theory using grounded theory analysis as described by Strauss and Corbin (1998). The theoretical model presented in this research can provide guidelines to educators in making decisions in implementing GIS and this system in their respective curriculum at other Universities.

The adoption of GIS into the Civil Engineering curriculum is challenging due to the time required to develop GIS learning modules and, moreover, the time and effort required for educators to become familiar with GIS methods. Making GIS tasks to fit in a 2-hour laboratory session without increasing the number of laboratory sessions for an already packed schedule is equally challenging. The system under consideration could potentially alleviate these logistic issues.

This research is still in progress. At this moment, a GIS learning module for Surveying is being compiled and another set of data collection for the existing module will be carried out in fall 2008. Student's suggestions for improving the learning module are being implemented in the latest surveying module. Similar updates are being carried out in the existing modules as well.

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