AC 2010-2216: LONGITUDINAL EVALUATION OF A LEARNING SYSTEM FOR TEACHING GIS WITHIN THE CONTEXT OF A GEOTECHNICAL PROBLEM

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Abstract:

A learning system, to train civil engineering students to apply Geographical Information Systems (GIS) in geotechnical problems, was evaluated over a period of 5 years, hence longitudinal. The system was tested with a series of iterations consisting of usability tests and subsequent modification, which were followed by a series of applied evaluations within the context of class lab sessions. The principal goals of this evaluation were to determine the overall effectiveness of the system and the factors that affected student learning. The first evaluation was conducted in 2004; and included a control group that played a “game” related to the content to be learned and an experimental group, in which students used the system in their lab. This was followed by an evaluation in 2008, which included an experimental group and no control group. In 2009 students who used the system in lab with a teaching assistant were compared with those who did the lab as a homework assignment. Across all experiments, compared to groups who used the learning system, the students in the 2004 control group rated their perceived learning, motivation, and real world learning significantly higher, but scored significantly lower on an objective quiz over the materials covered in the lab. In the 2009 study, students who used the system on their own scored significantly higher on the objective quiz than those who used the system in class. Further, students in all experimental groups rated their knowledge, following the uses of the system, higher than their perceived knowledge before using the system, where they were only exposed to textbook and lectures. Also, students across groups rated the lab as more motivational, effective for learning, and related to “real world” engineering. From these results we can infer that the students who used the learning system gained more knowledge regarding the geotechnical module than a control group students who were, nevertheless, more enthusiastic in their lab ratings. Further, the system appears to be effective as a stand-alone system, as compared to use within the context of a lab session.

Introduction:

Geographic Information System or Geographical Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features present on the Earth’ surface and the events (non-spatial attributes linked to the geography under study) that take place on it. The phrase “to represent digitally” is used to convey the meaning “to convert analog (smooth line) to digital form.” They began working on the development of the GIS software in late 1950s, but the first GIS software was developed only in the late 1970s by the lab of the Environmental Systems Research Institute.
Evolution of GIS has transformed and revolutionized the ways in which planners, engineers, managers etc. conduct the database management and analysis.

GIS has been defined in many ways, ESRI an industry leader in GIS software and geodatabase 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”.

**GIS and Civil Engineers:**

Geographic Information Systems (GIS) provide the civil engineer with tools for creating, managing, analyzing and visualizing all types of geographic information. Using a central GIS database, spatial analysis can be conducted, data can be overlaid, other solutions and systems can be integrated to GIS. This way GIS is playing an increasingly important role in civil engineering by supporting all phases of infrastructure management.

A web-based e-learning system to facilitate integration of GIS into the Civil Engineering curriculum was developed, in order to repeat the exposure of this tool to students in the civil engineering curriculum. The Geotech module used for the management and presentation of geotechnical data was incorporated in the existing courses without having to increase the amount of credit hours. The learning system which was developed for the civil engineering curriculum focuses on a geotechnical application. The module consists of a comprehensive problem and an associated repository of learning objects organized using a progressive scaffolding approach. The system consists of three parts, introductory knowledge in civil engineering, GIS (Arcview® software), and an applied problem. The system was designed to be used in the classes where students are learning civil engineering concepts and also have a first order working knowledge of these concepts. The student’s knowledge of GIS is diverse, since the course where the system is being tested is multidisciplinary with students from various engineering disciplines like civil engineering, architectural engineering, and geological engineering. This diversity of previous knowledge was an important factor while designing as it had direct impact on the performance of the students. The overall goal of this project was to evaluate the effectiveness of the module, which covers geotechnical engineering and, to identify factors that mediate this effectiveness based on the data collected from students who used the e-learning system in the form of lab sessions and homework assignments from 2004 to 2009.

**Literature Review:**

**Progressive Scaffolding:**

In the learning tool being evaluated, students can choose from multiple levels of support, such as text, or detailed videos of the task, in order to match the optimum level of
assistance they require. “Progressive Scaffolding” is the term that is used to refer to this systematic method of providing learners with an optimal level of guidance \(^4\). The learning system was designed based on the progressive scaffolding approach where the supporting materials were offered in a progressive fashion from the most general and minimum guidance (text) to the most specific and detailed (video).

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 \(^4\). As a result, only two levels of scaffolding were provided to the participants in the Geotech/GIS system.

**Method:**

Note that the study was conducted in the years 2004, 2008 and 2009. In the year 2004 the learning system was introduced, it was a one year project funded by an NSF Course Curriculum and Laboratory Improvement (CCLI) proof of concept grant. This project resumed in 2008, since this was when the CCLI full development proposal was funded.

**Participants:**

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

The details of participants over the years are listed below:

**2009:** The students completed the assignment in the lab.

**2009:** The students completed assignment as homework.

**2008:** The students completed assignment in lab.

**2004:** The students completed assignment in lab.

**2004:** The students learnt about borrow sites via game, rather than learning system – control group.

**Materials:**

Students were asked to solve a specific problem related to soil borrow site selection using the GIS learning system developed. A series of steps were provided by the web based
learning system in order to support students in using commercial GIS software (ArcGIS/ArcMap). 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

In the web-based e-learning system, the instruction pages were provided to the students for solving the soil borrow site selection problems as well as problems related to translating ArcGIS data into useful information. The instruction pages had two sections, one on the left and the other on the right side. On the left side a collapsible navigation menu was provided with the labels of all the steps required and on the right side detailed description for each item that was selected in the left column was provided. Keeping in mind the progressive scaffolding approach, the contents in the right column consisted of a test version of the activities necessary to carry out the exercise as well as the link for the video version.

In the earlier years of evaluation students filled out a questionnaire a day after completing the lab exercise where as in the recent time the questionnaire was filled out by the students exactly a week after their lab session. The questionnaire included a series of 9-point likert scale questions ranging from 1 (strongly agree) to 9 (strongly disagree) based on the learning outcomes like:

*Perceived learning:* I learned a great deal about soil borrow site selection from (lab vs lecture vs text).

*Motivation:* I found (lab vs lecture vs text) to be very motivational.
**Perceived Application:** The (lab vs lecture vs text) was applicable to “real world” engineering.

**Perceived Knowledge:** I knew a great deal about soil borrow sites (before vs after) lab session.

**Quiz:** A technical quiz was conducted over soil borrow sites.

The likert scale questions were intended to evaluate student perception of laboratory activity in terms of learning (text and lecture)\(^\text{10}\). In addition to the likert scale questions there were two specific open ended questions pertaining to strength and weakness of the laboratory activity. A technical quiz was conducted at the end of the questionnaire on soil borrow site selection to evaluate student learning during the laboratory session.

**Procedure:**

This evaluation being a longitudinal one was conducted in the years 2004, 2008 and 2009. Over the years the Geotechnical Module was tested on different groups.

**2004 Evaluation:**

In the year 2004, there were 2 experimental conditions, learning system (GIS group) vs. traditional lab (control group), were assigned to two different laboratory sessions\(^\text{7}\). Students in each laboratory session 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 the 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\(^\text{7}\). 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 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.

2008 Evaluation:

In the year 2008, 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 a 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 the appropriate data. 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 a questionnaire and to complete a quiz that consisted of a series of technical questions related to soil borrow site selection.

2009 Evaluation:

In the year 2009, there were 4 different sections of “CE 215: Fundamental of Geotechnical Engineering” course where 2 sections took the lab session as a homework assignment and the other 2 sections did it as a regular lab session. Each regular lab session was 2 hours long and each session was carried out on Monday (homework assignment) to Wednesday (regular lab session). In the labs included in this evaluation, the students were briefed on the soil borrow sites before the lab and were also provided with a concept of soil borrow sites along with printed lab directions before the start of the lab 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 were provided with computers having GIS software (ArcGIS/ArcMap) pre installed along with the learning system open in a web browser. The students were asked to sign a consent form before the lab session. At the beginning of the lab session students had to download the data set i.e. the shape files required to perform the tasks. The lab deliverables included a statement with regard to the site selected, list of lab tests and results from the soil test, materials and delivery costs as well as the GIS map of the construction
and borrow sites along with appropriate data. In case the students found it hard to do the lab on their own, they were allowed to pair up in a group of two. At the end of the regular lab session the students were asked to submit the deliverables whereas for the ones who took it as a homework assignment, they had a week to complete and turn in the deliverables. A week after finishing 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 borrows site selection.

**Statistically Significant Results:**

**Results:** The results were measured based on the answers from the questionnaire, which was developed keeping in mind the learning outcomes.

**Perceived learning:**

Results below display students’ ratings of the degree to which they “learned a great deal” based on their response to three questionnaire items referring to lecture, lab and text. These ratings were analyzed using two-way mixed Analysis of Variance (ANOVA) with learning method (lab vs. lecture vs. text) as a within-subject independent variable and group (09 homework vs. 09 lab vs. 08 lab vs. 04 lab vs. 04 control) as a between-subject independent variable, and ratings as the dependent variable. A significant main effect was found for learning method. Post-Hoc analyses indicated that the students rated the lab significantly higher than the lecture, which they rated significantly higher than the text. No other effects were significant.

![Figure 2: Results for Perceived Learning](image)
Motivation:

Results below display students’ ratings of the degree to which they found a given learning method to be “motivational” based on their response to three questionnaire items referring to lecture, lab and text (see sample questionnaire in appendix…). These ratings were analyzed using two-way mixed Analysis of Variance (ANOVA) with learning method (lab vs. lecture vs. text) as a within-subject independent variable and group (09 homework vs. 09 lab vs. 08 lab vs. 04 lab vs. 04 control) as a between-subject independent variable, and ratings as the dependent variable. A significant main effect was found for learning method. Post-Hoc analyses indicated that students rated the lab significantly higher than the lecture, which they rated significantly higher than the text. In addition a significant main effect for group was found with those in the 04 control group rating motivation as significantly higher than all other groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>2009 Homework</th>
<th>2009 Lab</th>
<th>2008 Lab</th>
<th>2004 Lab</th>
<th>2004 Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab</td>
<td>5.81</td>
<td>5.81</td>
<td>5.60</td>
<td>5.93</td>
<td>6.22</td>
</tr>
<tr>
<td>Lecture</td>
<td>4.94</td>
<td>4.0</td>
<td>5.14</td>
<td>5.17</td>
<td>3.04</td>
</tr>
<tr>
<td>Text</td>
<td>4.72</td>
<td>4.19</td>
<td>4.25</td>
<td>3.04</td>
<td>2.52</td>
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</tbody>
</table>

**Figure 3:** Results for Motivation

<table>
<thead>
<tr>
<th>Group</th>
<th>2009 Homework</th>
<th>2009 Lab</th>
<th>2008 Lab</th>
<th>2004 Lab</th>
<th>2004 Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab</td>
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<td>4.35</td>
<td>4.65</td>
<td>5.17</td>
<td>6.56</td>
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<tr>
<td>Lecture</td>
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<td>3.45</td>
<td>4.28</td>
<td>4.45</td>
<td>3.07</td>
</tr>
<tr>
<td>Text</td>
<td>4.28</td>
<td>3.75</td>
<td>3.64</td>
<td>3.55</td>
<td>2.15</td>
</tr>
</tbody>
</table>
Real world learning:

Results below display students’ ratings of the degree to which the given method led to “real world learning” based on their response to three questionnaire items referring to lecture, lab and text (see sample questionnaire in appendix…). These ratings were analyzed using two-way mixed Analysis of Variance (ANOVA) with learning method (lab vs. lecture vs. text) as a within-subject independent variable and group (09 homework vs. 09 lab vs. 08 lab vs. 04 lab vs. 04 control) as a between-subject independent variable, and ratings as the dependent variable. A significant main effect was found for learning method. Post-Hoc analyses indicated that students rated the lab significantly higher than lecture, which they rated significantly higher than the text. No others effects were significant.

![Figure 4: Results for Real World Learning](image)

<table>
<thead>
<tr>
<th>Group</th>
<th>2009 Homework</th>
<th>2009 Lab</th>
<th>2008 Lab</th>
<th>2004 Lab</th>
<th>2004 Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab</td>
<td>6.94</td>
<td>7.21</td>
<td>7.59</td>
<td>7.62</td>
<td>7.89</td>
</tr>
<tr>
<td>Lecture</td>
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<td>5.0</td>
<td>6.13</td>
<td>5.76</td>
<td>3.96</td>
</tr>
<tr>
<td>Text</td>
<td>5.66</td>
<td>5.58</td>
<td>5.11</td>
<td>4.97</td>
<td>3.31</td>
</tr>
</tbody>
</table>

Pre Knowledge vs Post knowledge rating:

Results below display students’ ratings of their knowledge before and after their experience in the lab, based on their response to two questionnaire items, which asked them to rate the amount they knew about soil borrow sites before and after the lab respectively (see sample questionnaire in appendix…). These ratings were analyzed using two-way mixed Analysis of Variance (ANOVA) with learning method (lab vs. lecture vs. text) as a within-
subject independent variable and group (09 homework vs. 09 lab vs. 08 lab vs. 04 lab vs. 04 control) as a between-subject independent variable, and ratings as the dependent variable. A significant main effect was found for time with students rating their knowledge significantly higher after their lab experience.

![Figure 5: Results for Pre vs Post Knowledge Rating](image)

<table>
<thead>
<tr>
<th>Group</th>
<th>2009 Homework</th>
<th>2009 Lab</th>
<th>2008 Lab</th>
<th>2004 Lab</th>
<th>2004 Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Knowledge</td>
<td>3.88</td>
<td>3.14</td>
<td>4.45</td>
<td>3.59</td>
<td>4.33</td>
</tr>
<tr>
<td>Post Knowledge</td>
<td>6.16</td>
<td>5.62</td>
<td>6.45</td>
<td>6.35</td>
<td>6.93</td>
</tr>
</tbody>
</table>

**Post quiz:**

Students’ quiz scores were compared in a one-way between-subjects Analysis of Variance with group (09 homework vs. 09 lab vs. 08 lab vs. 04 lab vs. 04 control) as the independent variable and quiz score (percentage) as the independent variable. There was a significant main effect for group. Post-Hoc analyses indicated that those in the 09 homework group scored significantly higher than all other groups except for the 04 lab group, and the 04 control group scored significantly lower than all other groups.
Discussion:

2009 Lab Group:

The students in this group rated the lab activity higher when compared to the text and lecture for perceived learning, motivation and real world learning. They even rated their knowledge higher after the lab activity. Coming to the results of the post quiz, the 09 Lab Group scored the 4th highest among the others.

2009 Homework Group:

The students in this group rated the lab activity higher when compared to the text and lecture for perceived learning and real world learning. In terms of motivation they rated lecture higher than lab and text, and even rated their knowledge higher after the lab activity. The results from the post quiz show that the 09 Homework Group scored the highest among all the other groups.

2008 lab Group:

The students in this group rated the lab activity slightly higher when compared to the lecture and text for perceived learning, motivation and real world learning. They even rated their
knowledge higher after the lab activity. Based on the results from the post quiz the 08 Lab Group scored the 3rd highest among all the other groups.

2004 Lab Group:

The students in this group rated the lab activity higher when compared to the lecture and text for perceived learning, motivation and real world learning. They even rated their knowledge higher after the lab activity. Based on the results from the post quiz the 04 Lab Group scored the 2nd highest among all the other groups.

2004 Control Group:

The students in this group rated the lab extremely high when compared to lecture and text for perceived learning and motivation. They also rated the lab slightly higher than lecture and text for real world learning. This group rated their knowledge to be higher after the lab activity. Based on the results from the post quiz, we can infer that this group scored the least among all the others though they showed higher results for labs in terms of perceived learning, motivation and real world learning across all the other groups.

Conclusion:

Across all groups, students consistently rated the learning system more positively than class lecture or text, and rated their knowledge higher after carrying out the lab activity. In addition, students rated the laboratory significantly more applicable to real world learning than their class or lectures. Students in the control group in 04 rated the activity as more motivational, than groups that used the learning system. They also rated the lab activity high on perceived learning, real world learning, pre vs post knowledge. The students from the 09 homework group rated the least for perceived learning and real world learning. The results from the technical quiz show that the regular lab groups of 09, 08 and 04 showed almost the same results with a minor difference. However, those in the 04 control group scored lower than all other groups on the technical quiz, and those in the homework group in 09 scored significantly higher than all the other groups on the quiz.

Bibliography:


