AC 2011-1884: A WEB-BASED LEARNING MODULE FOR TEACHING GIS WITHIN THE CONTEXT OF ENVIRONMENTAL ENGINEERING

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A Web-Based Learning Module for Teaching GIS within the Context of Environmental Engineering

Abstract

There is a growing need for teaching Geographical Information Systems (GIS) in engineering disciplines, such as environmental. However, there has been limited focus on GIS in undergraduate programs, since it's difficult to fit a GIS class into the large number of class requirements already included in engineering curricula. The purpose of this research is the evaluation of web-based learning module created by a multidisciplinary team at a Midwestern technological research university, which allows instructors to integrate GIS instruction into existing courses. This module is one part of a large scale National Science Foundation funded project in which GIS modules are being developed for several areas in civil engineering. The principal goals of this evaluation are to determine the overall effectiveness of the module, identify the factors that mediate the effectiveness, and to determine ways in which the module can be made more effective.

Data were collected from 56 students, 28 in an experimental group and 28 in a control group. Students in an experimental group participated in a laboratory session, which utilized the module, to solve a problem on urban ozone events and census tract analysis; whereas students in a control group attended a class lecture covering the same information. Students in the experimental group completed a questionnaire and students in both groups completed a quiz over the material.

Quantitative analysis was carried out on the quantitative portion of the scale for the experimental group, and for both groups on the quiz. A qualitative analysis was applied to the open-ended questionnaire items for the experimental group. Students in the experimental (learning system) section scored significantly higher on the quiz. Students in the learning systems group 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 engineering than both their text books and class lecture. The qualitative analysis revealed a number of ways the system can be further improved to make the module more effective.

I. Introduction

A. Introduction to GIS

Geographic (or Geographical) Information Systems have been defined by Environmental Systems Research Institute (ESRI) 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"[1]. GoodChild (1995) has given various other defining features of GIS[2]:

1) The ability to store and analyze spatial relationships between objects, such as crosses, intersects, is adjacent to, or is connected to, or to compute them as required
2) The ability to store and analyze an unlimited number of attributes of each object
3) An emphasis on analysis, rather than simple data management and retrieval
4) The ability to integrate data from different sources, perhaps at different scales and using more than one mode of representation

In addition, Black et al. 1998 have identified five generic types of questions that can be addressed by GIS technology like location (what is at..?), condition (where is..?), trend (what has changed since..?), pattern (what is the spatial distribution of..?) and projection or model (what if..?)[3]. Location determines the attributes of a given place or region. Condition seeks locations fulfilling certain conditions. Trend determines changes in place attributes over time. Pattern investigates the spatial distribution of some phenomena. Projection or model explores potential patterns based on past data[3].

GIS is one of the newly developed technologies and also one of the most important components to global problem solving. GIS technology was developed approximately 30 years ago and already represents a billion dollar industry worldwide, growing at 25% per year and serving about one million persons on a daily basis in more than 100 countries. GIS technologies have been applied by a number of disciplines ranging from governments, nongovernmental organizations, businesses to educational institutions[4]. GIS differs from other information systems in that it has very powerful capabilities for data analysis and modeling and uses place to link the descriptive information from any number of different data sets[3].

B. GIS and Civil Engineering

The use of GIS in civil engineering applications is growing. Engineers understand the value of the relational capabilities and the potential of GIS in their respective discipline and fields of specialty. Most of the civil engineering applications involve data intensive exercises, based on geographical information that take the form of maps and photographs. The civil engineer has to analyze and interpret various forms of data, link and compare the georeferenced information as part of a design, or analysis task. Since these designs and analyses are time consuming and mostly done on hard copy, GIS technology can help the civil engineers to improve the methods used for the design and analysis of the spatial data and enhance the efficiency with their spatial analysis capability[5].

ESRI (2010) also indicates that the civil engineering projects may include the management, analysis and integration of large amounts of geographic information to ensure success. The information might either be in the form of detailed design drawings originating from CAD solutions, detailed mapping, air photography, geological investigations, population information, traffic flows and environmental models. Hence with the increasing complexity of the civil engineering projects, a significant tool is necessary for the effective and efficient data management and sharing solutions. GIS technology provides the civil engineers with the tools for creating, managing, analyzing and visualizing the data associated with developing and managing infrastructure. And this central GIS database can be utilized to conduct spatial analysis, overlay data and also integrate other solutions and systems. Hence, GIS has played a vital role in civil engineering[6].

C. GIS and Environmental Engineering

Environmental Engineering is one of the disciplines that focuses on the impact and mitigation of environmental contaminants. It provides solutions for managing water, air and waste. Since environmental issues are inherently spatial affecting a geographic location or area, their spatial dimension needs to be captured. GIS has proved to be successful in the handling, integration, and analysis of spatial data and has become an easily accessible technology. Hence, the link between GIS and environmental engineering provides various possibilities for improved environmental modeling and engineering solutions by building versatile decision support systems for managing and even saving the environment[7]. Thus, GIS provides a tool for the scientists, environmental managers, and engineers to study the environment, report on environmental phenomena and to model how the environment is responding to natural and man-made factors.[6] With the help of a digital map, GIS allows a user to see locations, events, features, and environmental changes. The GIS map shows various layers of information such as environmental trends, soil stability, pesticide use, migration corridors, hazardous waste generators, dust source points, lake remediation efforts, and at-risk water wells for effective environmental practice[8].

Although there are many disciplines where GIS is applicable, we will be focusing on the evaluation of an environmental web-based learning module created by Missouri S&T scientists and engineers to complement the GIS learning tool. The environmental module is a web-based learning system that facilitates the learning of civil engineering students to use many of the environment-related capabilities of GIS. The purpose of this study is to examine the value of this module, focusing on its effectiveness in aiding learning, ease of use, and real world applicability.

II. Literature Review

A. Teaching GIS

Because of the importance and impact of GIS, there is a growing need for GIS training. One of the principal barriers to more wide scale implementation of GIS is the lack of experienced personnel. Since people are one of the four major components in GIS development (other three being hardware, software and data), there exists an urgent need to have professionals knowledgeable in GIS technology[9].

Craver et al. 2004 note that although there are many computer-aided learning tutorial systems for GIS, they do not tend to be fully interactive and rely largely on the pre-cooked examples to demonstrate GIS methods with the result that student input and ability to explore concept and practical problem interactively and in depth is limited[10]. Hence, the need for the web-based learning system is the focus of the present assessment. The responsibility for creating and using GIS is shifting towards professionals knowledgeable in GIS technology and its implementation in non-GIS specialties such as civil engineering[11].

B. Teaching GIS in Civil Engineering

The discipline of civil engineering includes a wide range of specializations that are related to spatial-data processing. The specializations include geotechnical engineering, project management, highway design, municipal engineering, transportation engineering, urban planning, waste and wastewater management, environmental engineering, and so on. The integration of GIS into civil engineering is important in order to meet the urgent needs of non-GIS professionals in engineering and also to teach students relevant skills in spatial analysis, reasoning and data processing[9].

Luna et al. 2010 summarizes Joseph Bordongna, a former NSF director's viewpoint on how civil systems engineers will play a significant societal role. Joseph Bordongna observes that the current civil infrastructure is based on interconnected and complex civil engineering systems. These civil systems are spatially distributed in urban or rural settings and many of the decision regarding maintenance, rehabilitation and new construction require spatial reasoning. Hence he contends that civil engineers are the master integrators of these civil systems and they need to have a global perspective[11, 12].

C. A Learning System for Teaching GIS in environmental engineering

Research on teaching of GIS has been focused primarily on Geography[13, 14, 15]. Although this research has focused on very few disciplines and not significantly on environmental engineering, it is extremely important that a foundation be created to teach GIS in environmental engineering as well. As discussed above, there are various applications of GIS in environmental engineering. For example, GIS is able to handle, integrate, and analyze spatial data to solve environmental issues. GIS provides improved environmental modeling and engineering solutions by building versatile decision support systems for managing and saving the environment[7]. Hence, for the students to be aware and knowledgeable and be able to apply their learning in real situations, Missouri S&T scientists and engineers have developed an environmental web-based learning module to complement the GIS learning tool.

This evaluation is one part of a large scale National Science Foundation funded project that has been carried out over the last several years, in which a web-based e-learning system is being developed to facilitate integration of GIS into the Civil Engineering curriculum. The system consists of a number of discipline specific modules. The modules are being developed in such a way that they can be incorporated in existing courses without having to increase the amount of credit hours. The modules consist of comprehensive problems, which require the use of GIS software to solve. The system includes a series of tutorials to guide the student in solving these problems utilizing GIS software. The tutorials include multiple levels of media richness, an approach we refer to as progressive scaffolding[16, 17, 18, 19]. 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 students' knowledge of GIS is diverse, since the courses where the system is being tested are often 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. Hence, the primary goals of this project are to determine the overall effectiveness of the Learning System and to identify factors that mediate the effectiveness in order to modify and optimize the system[11, 19, 20, 21, 22].This evaluation is the first directed at the module over environmental engineering.

Research on the system so far indicated the GIS learning system is easy to use, useful, and motivational, in that it provides "real world" learning[16, 17, 18, 19, 20, 21, 22].To date, the evaluation of the system has focused on the first module to be developed, which covered geotechnical engineering. For example, students who used the Geotechnical module scored significantly higher than a control group, who carried out an alternative activity. Subsequent research served to replicate and extend these results with the Geotechnical GIS module[20, 21]indicating that students consistently rated the laboratory as significantly more effective for learning and motivation in comparison to the textbook. Qualitative analyses further supported findings that the lab activities enhanced the learning of core content, motivation and also its relationship to real world engineering. The results from a logistical analysis, which summarized the evaluations from 2004 to 2009, further demonstrated that students consistently rated the learning system more positively than class lecture or text, and also 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[22].

The first evaluation of modules, rather than the Geotech module, was an exploratory study conducted on a module covering GIS within the area of transportation. This study also indicated that the system scored higher in terms of student ratings learning effectiveness, ”real world” applications and motivation, in comparison to the text and class lectures. The qualitative analysis also suggested that the transportation module was considered to be helpful and well formatted with video components[23].Although an exploratory study, with a small sample, the results of this initial evaluation of the transportation module were consistent with the results of the geotechnical module evaluations. The purpose of this study is to further extend the evaluation of this learning system for teaching GIS within the context of Civil Engineering courses, by reporting on the first evaluation of the module covering environmental engineering. More specifically, the objectives of this research are to: 1) Assess the overall effectiveness of the module; 2) Identify factors that mediate the effectiveness; and 3) Determine ways in which the module can be improved.

III. METHOD

A. Participants

The participants for this research were fifty-six students enrolled in an undergraduate course “Env Eng 261: Fundamentals of Environmental Engineering” at Missouri University of Science and Technology.

B. Materials

The students in the experimental group (see procedure) were asked to use the GIS learning system developed to solve a specific problem related to urban ozone events and census tract analysis. The web based learning system consisted 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, urban ozone events and census tract analysis.

A quiz was used to evaluate student learning for both experimental and control group (see procedure). The quiz consisted of eight multiple choice questions on the topic of the lab, that is, “Urban Ozone Events and Census Tract”. Students in the experimental group also completed a post experimental survey. The questionnaire included a series of 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 and one open ended item which asked students to comment on how the lab activity could be improved.

C. Procedure

Two lab classes in the “Fundamentals of Environmental Engineering” course made up the experimental group and a control group. The experimental group had a lab session for 3 hours. The students were provided with a concept of urban ozone events and census tract analysis along with printed lab directions before the start of the laboratory session. The objectives of the laboratory session were to: 1) Improve the understanding of sources and chemistry of smog and how meteorology influences distributions across a metro region; 2) Connect air pollution data with the people affected; 3) Be able to evaluate whether a region is out of compliance for a pollutant; and 4) Determine if some regions or groups (such as children) are disproportionately exposed to pollutants. 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. 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 printing out of ozone map overlaying census tracks, with an arrow pointing in the direction the wind is blowing and identifying regions of high Nitric Oxide emissions; providing a final printout of Absolute average ozone levels added to census tract; and answering provided questions.

Students worked in pairs due to the lack of computers. The students had the option to submit the deliverables at the end of the lab session or as homework in class the next day. After finishing the laboratory sessions, students were asked to fill out the questionnaire and to complete a quiz consisting of a series of technical questions related to urban ozone events and census tract analysis.

On the other hand, the control group for the Environmental Engineering GIS module attended a class session where they were taught similar concepts to those presented via the GIS module. After the lecture, students were asked to complete a quiz similar to that of experimental group.

IV. Results

A. Quantitative Results

In order to compare students ratings of the lab (using the learning system), lecture, and class text, three one-way within-subject analyses of variance were performed on the data obtained from three sets of questions pertaining to perceived learning, motivation and real world application. The independent variables were the course components (lab vs. lecture vs. text) and the dependent variables were the ratings. All three analyses of variance were significant at $p<0.001$ level. The significance along with mean rating and Tukey's post hoc comparison are presented in Table 1.

Item	Course Component			Post Hoc
	Lab	Lecture	text	
Learning	7.68	5.75	3.04	Lab > Lecture > Text
Motivation	6.56	4.89	2.33	Lab > Lecture > Text
Application	7.32	5.96	6.00	Lab > (Lecture & Text)

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

In order to compare the experimental (learning system) and control (lecture) groups, a between subjects t-test was computed with condition as the independent variable and quiz as the dependent variable. The groups differed significantly ($p<0.05$) – with those in the learning system group (71.43%) scoring higher than the students who were taught similar concepts in a class session (61.6%).

B. *Qualitative Results*

The qualitative analysis revealed a number of ways the system can be further improved to make the module more effective. The responses from participants were analyzed, coded and categorized. The quantitative question asked to the participants was "Please list ways in which the lab activity could be improved." The responses were coded and categorized as: Design, Context and Length.

Design related to the statements pertaining to *simplicity* and *easiness of use* of the learning system. Participants suggested that the learning system was sometimes confusing and expected the system to be easy to use and understand. Although the videos that showed each step were good, it was said that the participants were not sure about what to look for on each step. "Make the GIS part much simpler so that it can actually be finished on time", one participant noted. The other participant said, "Too in depth for a starting tutorial". One of the participants also suggested focusing more on air pollution with less technical steps.

Context related to the statements focusing on improving directions. Participants suggested that the directions need to be clear. One of the participants was satisfied with the videos that showed the steps and the directions given but was unclear about what he/she was looking in each step. The other participant said, "Liked step by step guidelines. Wanted to know why I was doing the steps. What was it showing me? What is the relevance?" Most of the suggestions given by participants were to provide a better explanation of what each step meant and why they are inputting certain information. "Tell us what we are doing in the program and tell us how it pertains to air pollution", another participant noted.

Participants were not very satisfied with the length of the lab session. Most of the participants suggested making the length of the lab shorter. "Make it shorter, make it slightly easier, make it more interesting", one student said. "Start out slow, don't try to make us learn the whole program at once", another student suggested. Hence, participants suggest conducting more than one lab rather than having them do everything at once.

V. Conclusions

The quantitative analysis supported the overall effectiveness of the module. The quantitative analysis indicated that students in the learning systems group 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 engineering than both their text books and class lecture. Furthermore, students in the experimental (learning system) section scored significantly higher on the quiz than the control section.

The other objectives of this research were to identify factors that mediate the effectiveness and to determine ways in which the module can be made effective. Qualitative analysis indicated that with some improvement on the factors like design, context and the length of the laboratory session, the learning system can be made more effective.

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