AC 2008-2791: INTRODUCTION OF GIS INTO CIVIL ENGINEERING CURRICULA

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Introduction of GIS into Civil Engineering Curricula

Abstract

This research project developed a web-based learning system to teach students the use of Geographic Information Systems (GIS) within the foundational courses of a typical civil engineering program. As opposed to generating a series of GIS courses, the GIS know-how is introduced within existing courses as a module that will reinforce basic concepts taught throughout the curriculum in a comprehensive manner. Evaluation research of a proof-of-concept prototype for geotechnical course supported the efficacy of such an approach. With this prototype as a guide, modules are developed in the following five areas: environmental, geotechnical, hydrology, surveying/measurements, and transportation.

The principal objectives of this research project are: (1) To create a web-based learning system that supports student learning on how to apply GIS within the context of civil engineering, (2) To implement learning modules in existing undergraduate civil engineering courses, (3) To carry out a series of summative and formative evaluation studies (including external evaluators) with components and iterations of this learning system under development, and, (4) To disseminate the developed educational materials and learning system to other universities in order to test the ability of our results to scale and port. The GIS tool and the Civil Engineering content were selected because of the importance of these disciplines within the engineering profession and within the broad context of current U.S. infrastructure needs. The design approach introduces GIS to both the student and instructor during the learning experience. The instructor's focus is still the subject matter in civil engineering. The design of the instructional tool consists of training in the use of GIS within the context of real Civil Engineering problem solving. The design of the learning system is firmly grounded in educational theory and research. Further, educational evaluation and research comprises a major component of this project, which extends research carried out in the proof of concept project. This includes the detailed exploration of learning and instructional design variables, utilizing multiple methodologies and measurement tools. This research, combined with our initial findings, yields a detailed understanding of how students go about using interactive software to learn to use sophisticated tools to solve complex problems. This provides important insights into basic cognitive and educational issues that underlie learning with these types of learning technologies. The expansion project is designed with a broad scope to cover several emphasis areas in civil engineering and the impact of engineering decisions to the public. Almost all civil engineering programs in the country have required courses such as the ones presented herein. The evaluation process includes peers and colleagues from at other universities for an external loop in the development of the learning system to ensure a superior quality product. Civil engineering programs nationwide will benefit from the integration of GIS into their foundational courses without adding more courses. Nationwide access benefits the engineering profession as a whole, as newly minted engineers begin their careers with a strong GIS background.

Introduction

The popularity of web-based instructional tools across engineering disciplines has grown significantly in recent years[2-4] for a number of reasons. First, a much larger number of students, and a much wider audience can be reached via the World Wide Web. These web-based classes can have distinct advantages over traditional distance education, in that the web allows for much richer media than paper and pencil classes, and the cost is a fraction of that required for elaborate satellite-based video technologies. Second, web-based learning environments can be made adaptive so that they are sensitive to learners' abilities and styles. Third, there is evidence that hypermedia can provide an effective representation of complex physical models that are fundamental to engineering education[5]. Fourth, the web-based learning environment can be interactive and flexible in a way that a textbook cannot, by allowing learners to be more flexible in their traversal of the information space. These tools can respond instantaneously to learners' data inputs with numerical and graphical responses, and can provide a vehicle for structuring and promoting communication[6]. At another level, web-based presentation of content can free the classroom instructor from the limited and passive task of traditional lecture, leaving class time for more active learning scenarios such as collaboration and one-on-one instruction. Finally, all of these methods have an advantage over traditional software tools since they are available to anyone with a web browser and internet connection, and they allow for networking beyond a set group of computers to connections around the globe.

Research indicates that much of the promise of these learning systems has not been fully realized[6, 7]. The primary reason is that little thought or effort goes into design and research before the tools are implemented[8]. A fundamental characteristic of effective learning environments is that they promote and encourage active learning; and unlike many web-based courses and elaborate multimedia simulations, which simply are used to display information without requiring student interaction. At the same time, research in hypermedia learning systems indicates that it is also very important to provide a learner with some level of guidance, and this too is often lacking in these web-based systems. The vast majority of web-based courses and modules have not been pilot tested or evaluated prior to their introduction into the curriculum.

Computer-based learning systems and the World Wide Web afford us an opportunity to move engineering education to a new level, both to enrich traditional instruction and to provide instruction at a distance. However, such a transformation can only be realized through the application of systematic principles of instructional media design and through close interaction between content providers and web designers. This project is designed to do just this, through the development of a web-based guided system to teach students the application of GIS within the context of civil engineering curricula.

Need for Geographic Information Systems Instruction in Civil Engineering

GIS is a computerized database management system that provides geographic access (capture, storage retrieval, analysis and display) to spatial data. GIS provides an excellent means for students to manipulate and examine the complex data usually required in the design and analysis processes. Additionally, 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 is a need for civil engineers to be versed in GIS and to apply GIS tools to civil engineering problems in innovative ways. Few unified efforts in the civil engineering area have been made at universities to address this need. A basic response to the university customer needs is to provide students with some background in GIS.

The most visually distinctive feature of GIS software is a map display that allows thematic mapping and graphic output data overlaid onto a map image. The key element that distinguishes GIS from other data systems is the manner in which geographic data are stored and accessed. GIS store geographic data using topological data structures (objects' locations relative to other objects are explicitly stored and therefore are accessible) that allow analyses to be performed that are impossible using traditional data structures. Standard GIS functions include thematic mapping, statistics, charting, matrix manipulation, decision support systems, modeling algorithms, and simultaneous access to several databases. Both vector- and raster-based GIS tools are available to the engineer via a growing industry of software and data providers.

There exists a lack of qualified specialists with the ability to create and use GIS in academic institutions, companies and organizations. There is a consequent need to have professionals knowledgeable in GIS technology and its implementation in non-GIS specialties such as civil engineering. Approximately 80% to 90% of all information used by civil engineers has some spatial content. For example, civil engineers must have, and be able to apply, knowledge of land use, environmental, socio-economic, property and other administrative data. These kinds of information may be integrated using GIS tools[9]. Given the dramatic advances in data capture made in the past five years and the increasing complexities involved in civil engineering problems, students' ability to work from a systems perspective is more critical than ever. Bordogna, the former NSF director, summarized his view on how civil systems engineers will play an evermore significant societal role in this century[10]. He referred to civil engineers as the master integrators.

There exists an urgent need for civil engineering (CE) to incorporate GIS knowledge into the curriculum. Several of the evaluation criteria to which all CE programs are subject support this thesis as well. CE programs are also faced with the need to satisfy accreditation criteria as set forth by the Accreditation Board for Engineers and Technologists (ABET). Several of the outcomes listed in the ABET Criterion 3[11], for engineering programs, directly relate to skills that can be gained using GIS - for example, to analyze and interpret data or to design a system, and to use techniques, skills and modern engineering tools necessary for engineering practice. The integration of GIS into the classroom would enhance the transmission and acquisition of these skills and would be used to help CE programs in meeting ABET requirements.

The approach adopted for the development of educational materials is modular and shareable, allowing civil engineering curricula to offer GIS know-how without requiring additional courses, particularly with the current demands to reduce the total credit hours in the 4-year engineering programs. These modules can be a combination of data products and software delivered via web-based Intranet or Internet of the institutions.

WEB-BASED LEARNING SYSTEM

The learning system developed for the pilot project focused on a geotechnical application. The prototype consisted of a comprehensive problem and an associated repository of learning objects organized using a progressive scaffolding[12] approach (both discussed in more detail below). The learning objectives for the system can be broadly classified in three groups: foundational knowledge in civil engineering, training in the use of GIS, and application of concepts to modern engineering problems. The system is being designed for use in courses 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 could be diverse when they enroll in the course. For example, in the course where this system was first implemented there are students enrolled from three different majors (e.g., civil engineering, architectural engineering, and geological engineering). This may not be the case for other programs, but the diversity of previous knowledge was an important factor in guiding the system design.

Two important concepts were instrumental in the design of the prototype system, and will also guide development in the current expansion project. First, information was decomposed into sharable content objects compliant with ADL/SCORM requirements (ADL=advanced distributed learning; SCORM=Shareable content object reference model). Second, a progressive scaffolding approach was used for presenting different types of media.

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. 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*[13].

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 131111 tasked the Department of Defense (DoD) "to develop common specifications and standards for technology–based learning"[14] 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, with cost savings resulting in millions of dollars. However, university educational information networks have been slow to adopt and utilize these standards. 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 is a term used to refer to a systematic method of providing users with an optimal level of assistance. Within such a system, different levels or tiers of help 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 solve[15, 16]. 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 this 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.

GIS/Civil Engineering LEARNING SYSTEM

The civil infrastructure that we have built for our society is based on interconnected and complex civil engineering systems. These civil systems are spatially distributed in urban or rural settings and many of the decisions made require spatial reasoning. The civil engineer is positioned to be the master integrator of these civil systems[10] and they need to be trained to see the whole picture. GIS are ideally designed as computer-based tools to allow the engineer to design spatially distributed infrastructure. Traditional civil engineering curricula have a series of courses within areas of emphasis (e.g., geotechnical, transportation, environmental, water resources, construction, structures, surveying, etc.) and these are integrated in the final design (capstone) course. However, making comprehensive design decisions regarding realistic, complex and spatially distributed problems earlier in the curriculum is a superior learning experience.

In this expansion project, a learning system will be developed for civil engineering curriculum focused on at least five areas of the curriculum. The learning system will be designed in the first year and implemented in the second year of the project period into regular undergraduate courses. These courses are required for undergraduate students and will have a laboratory component in which the learning modules will be used and evaluated. These modules will focus on the application of fundamental concepts that were learned in previous sessions in that course or pre-requisite courses. The beauty of this approach is that the instructor will be learning GIS techniques along with the students as they follow the detailed instructions. The instructor will need to focus on the foundation course content and problem to be solved in the respective discipline.

In the proof-of-concept project, a prototype learning system was developed for civil engineering curriculum focused on the geotechnical area of emphasis by the PI. The prototype was implemented in the second semester of the project period as part of a regular undergraduate course in the Civil Engineering program – CE 215 Fundamental of Geotechnical Engineering. This course is required for all undergraduate students and has a laboratory component where the prototype learning system was used and evaluated. The learning objectives focused on the concepts of geology, soil classification, phase relations of soils, and compaction. The lab exercise required the student to select a soil borrow site for use as fill at a specified construction site. The engineering decision-making process of selecting borrow sites is complex and required more than one source of information. The desired type of soil needed to be determined. The decision depends on the engineering application (i.e., landfill liner, structural fill, drainage blanket, etc.). Potential borrow sites are located at different geographic locations and different factors affect their suitability for use as borrow material (i.e., access, soil type available, cost, distance from construction site, etc.). For the expansion project other faculty members have embraced the concept and have developed ideas to similar implementation into their courses, which are presented in the next section of this paper.

The learning system emphasized the principles of reliable and cost effective solutions, which are very important to civil engineers. Since the critical learning objective is to decide which soil borrow site to use for a particular construction objective, the issues of distance to the site, truck hauling costs and quality of material must be considered by the student. This information is provided via the GIS data learning objects incorporated into the learning system object repository. In combination, the complete set of learning objects provide an educational experience that exceeds what is traditionally obtainable via traditional textbook instruction supplemented with laboratory experimentation.

The applied problem was at the heart of the system, with the GIS learning objects providing support as needed. One of the common learning objects for this learning system is the "*ArcView ™* Basics" topic, which was created using several content objects. These content objects consist of a text and video representation of the following topics: opening a map, displaying labels, *ArcView ™* navigation bar, and adding layers. The video demos were created with *Macromedia's Robodemo*©, and they are web-viewable via *Flash*©. Figure 1 consists of a screen shot from one of the screens of the learning system displaying a learning object, and in Figure 2 there is an example of the corresponding captured video.

The web-based learning management system (Blackboard®) was considered instrumental in making the prototype operational within a 10-month period. The spatial data layers required for the St. Louis, Missouri geotechnical project were collected and assembled as a data package for the students to use in a laboratory session. The application was designed using a SCORM compliant protocol and worked well. A series of videos were developed and tested prior to launching the application and their usability tested (see "evaluation of prototype" below).

The web-based application is available now at its own domain as prepared in the proof-of-concept phase I. Wide dissemination of this project was not the intent focus in phase I, but evaluators are encouraged to access this website: **http://www.learn-civil-gis.org/.** There is no login required, you may access to learning modules and data.

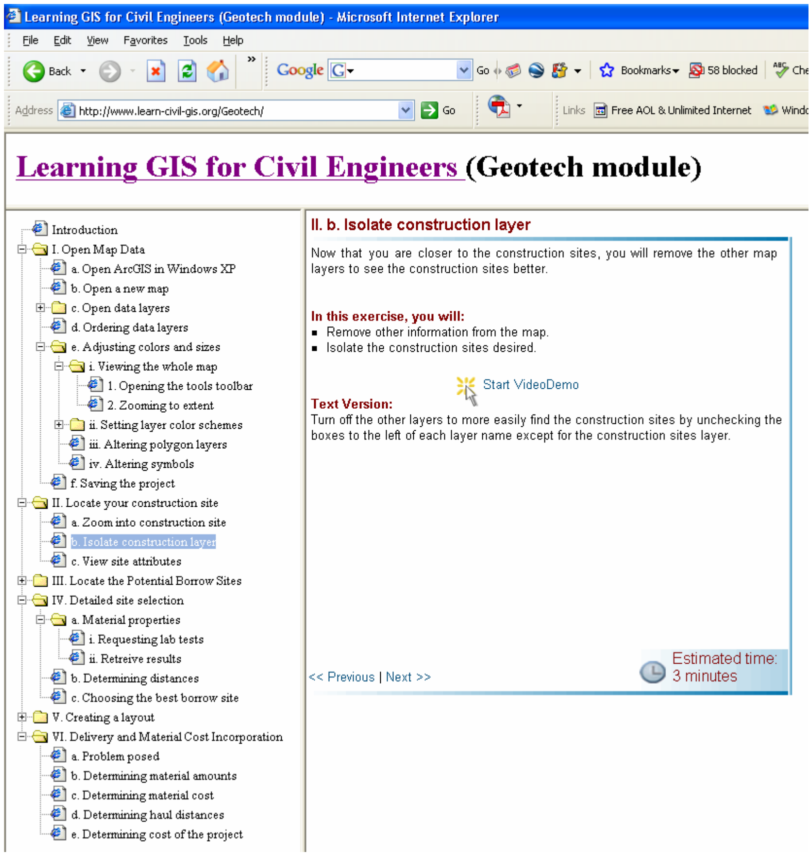

Figure 1: Typical web-based window of the learning management system (Geotech module)

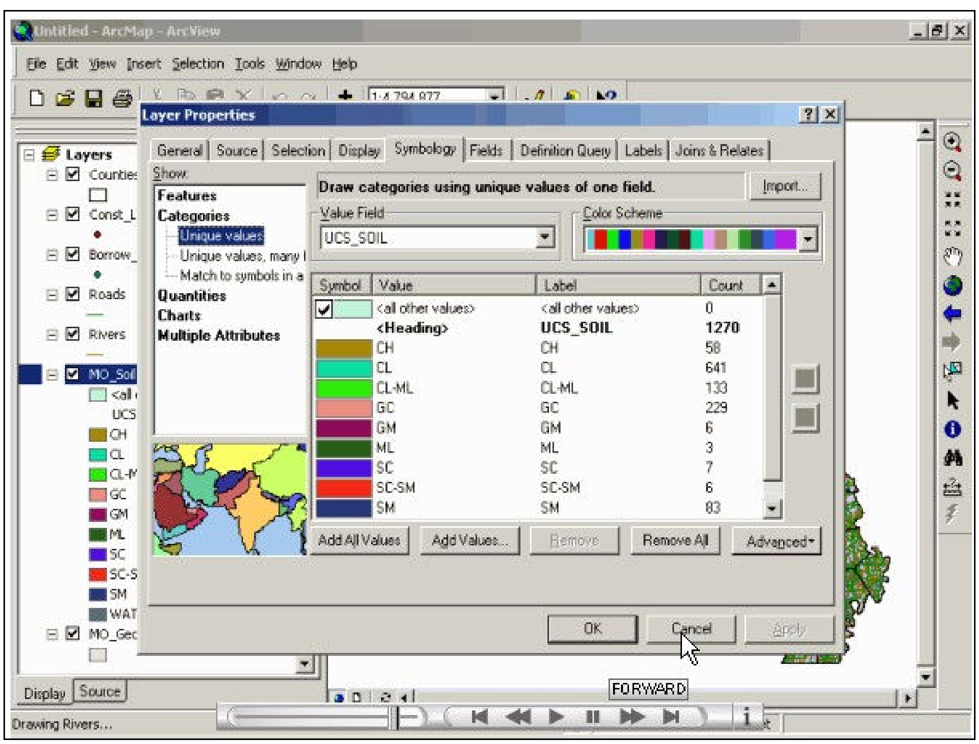

Figure 2: Video demo showing an example of the particular learning object

Based on the success of the prototype GIS learning system, the development of a full system in several areas of civil engineering is being developed. The modules will be developed for a 2-hour laboratory instruction period, which is typical for an afternoon session of an undergraduate course or as a homework assignment. Development and improvement will be based on the prototype system. The following paragraphs describe the approach to the current expansion project for each selected specialty area in civil engineering.

Surveying: Most of the information that a municipal government manages and archives are tied to specific geographic locations within its jurisdiction: property lines, easements, utility and sewer lines, and many categories of spatial data. Cities and municipalities need to manage property ownership, boundaries and the cadastral maps for legal and taxation purposes. Governments, land developers and property owners need and use this data in a daily basis. This is the basis for Land Information Systems (LIS) that run as an application of GIS. Usually a registered surveyor or civil engineer has the responsibility to generate the data for use in these systems. The ability to store, retrieve, analyze, report and display this public land information efficiently and accurately is of great importance. In the laboratory activity the students will use information generated by a surveyor to make a decision on the location of a major municipal utility within the city limits. Issues of property legal boundaries, valuation to purchase property and determining easements based on the available information will be some of the problems to be solved. The undergraduate course where development and implementation of this module will take place is CE 01 Surveying.

Environmental: Outdoor air pollution is generated by a variety of sources, most notably point sources, such as, coal-fired power plants. Regulators rely on mathematical models of pollutant dispersion and transport in order to estimate exposure to pollutants from these sources. The most common model for evaluating pollutant concentrations downwind from a point source is the "Gaussian Plume" model. These models are used to calculate the spatial distribution of pollutant concentrations for a pollutant at ground level or at elevation. By including variable atmospheric conditions in the model, a number of air pollution scenarios can be examined for most contaminants. Typically, students use these models to estimate the concentration of a pollutant downwind from a continuous or instantaneous point source. However, students often have difficulty visualizing their results unless they use graphical software. These scenarios tend to be academic, disconnected from the people and places that are affected. By combining plume models with GIS, we ground the academic exercise in reality and prepare the students for the regulatory components of engineering. The objectives of this GIS module are to: 1) improve the student's understanding of Gaussian plume modeling; 2) ensure that they connect their engineering calculations with real people; 3) demonstrate the process of exposure assessment; 4) have them evaluate whether a region is out of compliance for a pollutant; 5) demonstrate that some regions (often disadvantaged neighborhoods) are disproportionately exposed to air pollutants. The module will include several point sources located in a metropolitan area. Point sources may include power plants (emitting aerosols, mercury, NOx, etc.), dry cleaners (emitting trichloroethylene), etc. The students will find information about the climate (wind velocity and direction) and the source (mercury emission rate) and use them to develop parameters for a Gaussian Plume model. They will have several choices of model available and must choose the appropriate model depending on the type of source and pollutant. Once the plume has been generated and a visual representation is shown, it is overlaid onto the metropolitan area GIS grid.

The students can then begin to determine the extent of exposure and also determine which regions are most heavily exposed. The GIS grid will include population density census tracts. Provided with regional air quality targets, students will now be able to determine if the source has the potential to drive the region or a neighborhood out of compliance with the Clean Air Act. They will also find that they need to vary the wind speed and direction to incorporate the most probable atmospheric conditions. In this way, they make sure that all conditions are considered when making regulatory decisions. The undergraduate course where development and implementation of this module will take place is CE 261 Fundamentals of Environmental Engineering & Science.

Water Resources Engineering: The engineering decision making process of selecting spatially varying hydrologic parameters for most existing watershed models requires conceptualization of the components of the basin. This module reduces the requirement for conceptualization by managing voluminous spatial input data. This module emphasizes the spatial input data of soil classifications, land use, land cover, drainage areas, precipitation, and land slope within a watershed. The problem to be solved will be the determination of spatially varying hydrologic parameters from spatially varying input data and the presentation spatially varying output of flooding information such as velocity, depth of water, flooded areas or flood maps which show areas of inundation. Initially the students will use DEM (digital elevation model) data from the USGS and then transform this data into a spatial model of the topography that will represent the overland (flow over the surface of the ground) and open channel flow components (e.g., swales, drainage paths, streams, etc.) of the watershed. The required parameters used in the hydrologic model are spatial variables, such as, overland and channel roughness (Manning coefficients), precipitation abstraction parameters (Soil Conservation Service Curve Numbers), and the spatially varying precipitation event. Then, a hydrologic model will be run by the students outside of the GIS (e.g., HEC-HMS or SWMM) to obtain model output. For example, different rain storm events can be used in the model and areas within the watershed can consist of different areas of paved or unpaved areas that will correspond to different roughness coefficients and infiltration rates. This approach can be used to illustrate the influence of varying land use and topography on overland and channel flow characteristics, including the effect of urbanization on the distribution of flow depth and velocity as well as the resulting hydrograph and flooding. Finally, the students will take the results of the model and overlay them on top of maps with other civil information, such as roads, houses, and other structures to present the impact of their analysis on the public. The undergraduate course where development and implementation of this module will take place is CE 234 Water Resources Engineering.

Transportation: This module will guide students through the process of evaluating highway corridor alternatives and will delve more deeply into the process by visualizing the different alternatives in much more detail than what is possible without the use of GIS. Students will choose the "best" alternative and prepare maps using GIS to present their selection to stake holders such as the State (Missouri) Department of Transportation. At the planning stages of a highway project various location alternatives are explored, subject to design and resource constraints. Alignment impacts such as extent of right-of-way, quantity of earthwork, affect on land use, impact on water quality, wetlands and historic sites, all sensitive to geography, must be estimated and assessed for each alignment alternative. In a conventional introduction to transportation laboratory project, students are required to realign an existing highway to increase the existing speed limit to match with other sections of the roadway thus improving traffic flow and traffic safety. Students are asked to propose and evaluate alternatives based on availability of right-of-way, engineering judgment, design constraints, project cost and balance of cut and fill. Given the scale of these issues and the iterative nature of design, it is difficult for students to visualize the impact of e.g. realigning an existing highway or propose a new roadway that blends in with existing conditions. A GIS approach with ease of superimposing multiple layers of information, such as aerial photographs, contour maps, location of utilities, wetlands, grave yards, historic sites, existing structures such as roadways, bridges, and other features, would not only enhance their involvement but would provide a broader perspective and learning opportunity. *The undergraduate course where development and implementation of this module will take place is CE 211 Transportation Engineering (Dr. G. Bham, instructor).*

Geotechnical: Since this module was already developed (and previously described) in the proof-of-concept phase, only improvement to the delivery of the systems will be required. The undergraduate course where development and implementation of this module will take place is CE 215 Fundamentals of Geotechnical Engineering.

Summary

This paper presented the GIS learning system currently under development. Overall the GIS learning system developed to date has proven to be a successful pedagogical tool at the undergraduate level. Evaluation and testing of the developed learning modules has been completed but were not presented in this paper. Based on the results of the proof of concept project, there is a strong probability that the learning modules can be effectively expanded to other disciplines within civil engineering. Students that follow the curriculum will significantly benefit from multiple exposures to GIS within different applied contexts. The problem solving approach to the exercises that involve spatial reasoning and looking at the bigger picture of engineering will form engineers that are more aware of the broad impact sustainable solutions.

Acknowledgements

The authors would like to acknowledge the students and faculty from the University ________. This material is based upon work supported by the National Science Foundation under Grant Nos. DUE-03XXXXX and DUE-07XXXXX. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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