GIS Integration Across a Civil Engineering Curriculum

Stephanie Ivey[1], Paul Palazolo[2], Charles Camp[3], Anna Phillips Lambert[4], and David Arellano[5]

Abstract

One critical element of civil engineering is the ability to visualize the economic, social, environmental, and political consequences impact that design decisions will have. Geographic information systems (GIS) enable users to visualize some of these factors and are becoming a critical tool for the civil engineering design professional. In an effort to enhance students' learning experiences not only by actively engaging them in the learning process through a design-based approach, but by also providing the opportunity for students to become proficient in state-of-the art software applications typical in the civil engineering workplace, faculty in the Department of Civil Engineering at The University of Memphis have developed a GIS lab through Technology Access Fee (TAF) grant funding. Phased implementation of GIS is incorporating progressively more complex and challenging projects throughout the civil engineering curriculum.

Keywords: GIS, data visualization, curriculum modification.

INTRODUCTION

Technological knowledge, skills, and applications are important contributors to the academic success of all students, but for engineering students, these skills and strategies are critical components required for professional practice in the 21st century. In response to the ever-increasing technological advances, engineering educators face challenging instructional strategies of teaching the core content of traditional engineering pedagogy while integrating knowledge of current technological tools and applications used within professional practice without adding credit hours to existing programs[1].

The faculty in the Department of Civil Engineering in the Herff College of Engineering at The University of Memphis is committed to providing a challenging yet rewarding experience for students through excellence in

[1] Department of Civil Engineering, The University of Memphis, 104 Engineering Science, Memphis TN 38152, ssalyers@memphis.edu

[2] Department of Civil Engineering, The University of Memphis, 104 Engineering Science, Memphis TN 38152, ppalazol@memphis.edu

[3] Department of Civil Engineering, The University of Memphis, 104 Engineering Science, Memphis TN 38152, cvcamp@memphis.edu

[4] Department of Civil Engineering, The University of Memphis, 104 Engineering Science, Memphis TN 38152, darellan@memphis.edu

[5] Department of Civil Engineering, The University of Memphis, 104 Engineering Science, Memphis TN 38152, darellan@memphis.edu

teaching and evolving instructional methodologies. This is evident from the number of faculty that have attended teaching workshops geared specifically toward engineering educators, the ongoing research efforts to identify factors leading to attrition from engineering programs, nationally recognized efforts in research in instructional strategies, and the willingness to take innovative approaches to curricular design. The civil engineering department was a leader in the integration of a team-based design strategy into the freshman and sophomore curriculum, resulting in an award winning paper and an improved student experience[2]. The faculty collaborating on this project seek to continue to improve learning experiences for students through the incorporation of a state of the art technology in the civil engineering classroom.

PROJECT DEFINITION

Currently, the freshman and sophomore civil engineering curriculum includes a sequence of four required courses that involve students in content rich design as an introduction to the civil engineering profession. In addition to these courses, several design intensive courses are required in the junior and senior years, with the culmination in an integrative capstone Senior Design experience. While the curricular strategy is appropriate and successful, this project seeks to further enhance students' experiences by integrating a state-of-the art technology across the civil engineering curriculum.

One critical element of civil engineering, as demonstrated consistently by constituent survey data, is the ability to visualize the economic, social, environmental, and political impacts that design decisions will have. Geographic information systems (GIS) enable users to visualize the interrelationship of technical and non-technical factors and as such are becoming a critical tool for the civil engineering design professional. With this project, a GIS lab was established that is accessible to all civil engineering students, and faculty are incorporating projects throughout the civil engineering curriculum that use GIS software applications as a tool in the development of design solutions.

The goal of this project is to enhance students' learning experiences not only by actively engaging them in the learning process through a design-based approach, but by also providing the opportunity for students to become proficient in state-of-the art software applications typical in the civil engineering workplace.

BACKGROUND

Engineering programs have traditionally been plagued by dramatic attrition rates, and recent studies also indicate declining enrollment in engineering programs by high school graduates[3,4]. Typically, 40-70% of students originally enrolled in engineering leave the program before completion of the degree[5]. Over the past few years, the Civil En-gineering program at The University of Memphis has reported attrition after the freshman year at a rate ranging from 30 to 50%. These statistics are of particular concern given that engineering programs do not typically attract students from other fields, but instead rely mostly on retaining students who originally enroll in engineering[6].

Studies have shown that contrary to popular belief, the students leaving engineering are not "unqualified." [7] In fact, the grade distribution of students leaving engineering programs tends to be very similar to those who are retained[8,9]. Seymour and Hewitt examined students' reasons for leaving engineering, and found that one of the key factors was dissatisfaction with instructional methods[10]. Engineering courses have traditionally been lecture-based, and use of other teaching techniques has been limited. Many recent studies have shown that retention of engineering students is improved by introducing design applications early in the curriculum, and by exposing students to technology and software comparable to that they will use in the workplace so that students are better prepared for their professional careers[11-18].

Another common complaint of students leaving engineering programs is that introductory courses are not relevant to civil engineering practice[19]. Geographic Information Systems (GIS) have become an engineering standard for developing, analyzing, managing, and displaying geographic information. In civil engineering, GIS has become vital to the success of projects in many areas including environmental impact, site development, hydraulics, hydrology, transportation, planning, and public works. In particular, GIS provides a unique combination of complex relational databases, comprehensive spatial analysis tools, and powerful 2D and 3D graphical displays that allow engineers to better manage information for design and modeling. The development of GIS competence among civil engineering students is a critical component in preparing graduates for the workplace[20-24]. Thus, the purpose of the project

proposed herein is to address these issues through the introduction of content-rich design projects based in a GIS environment.

OVERALL OBJECTIVES

The objectives for this project include:

- Improving retention of civil engineering students through more engaging design-based approaches using GIS technology integrated throughout the curriculum;
- Creating an exceptional civil engineering educational experience by providing students access to GIS applications from the first semester of the freshman year, thereby strengthening recruiting opportunities; and
- Preparing graduates for the civil engineering workforce by enabling students to develop GIS related skills that are extremely marketable, and further enhancing their project design experiences.

ANTICIPATED OUTCOMES

The anticipated outcomes for this project include:

- Retaining a larger percentage of students by immersing them in state-of-the-art approaches to civil engineering problems from the beginning of the curriculum;
- Improving recruiting capabilities for the civil engineering program at The University of Memphis by offering a distinctive program designed to better prepare graduates for challenges they will face as engineers;
- Developing a student body competent in GIS applications that will make our department more competitive in seeking outside grants/contracts involving civil engineering projects integrating GIS database development, analysis, and model construction;
- Creating the opportunity for the eventual extension to an outreach program targeted toward exposing students in the K-12 age group to opportunities available in civil engineering;
- Providing the opportunity for a "ripple effect" throughout the civil engineering program as other faculty are able to use the equipment and lab facilities funded by this grant to incorporate "real-world" design experiences into additional courses in the program.

PROJECT RESOURCES

The main focus of this project was to create a GIS laboratory for civil engineering students, and to purchase a laptop cart for use in classroom demonstrations and software training. The laboratory consists of twelve Dell OptiPlex machines with a Dell Precision Mini-Tower machine used as a server. The GIS software requires high graphics capabilities, and the OptiPlex machines were selected to meet these specifications. A black and white laser printer and a 24-inch color plotter were also purchased for the lab. These printers were selected to handle the high volume expected from this lab, as well as the need to be able to produce large-scale plots for many design projects.

A 24-unit laptop cart was also purchased for use in the civil engineering courses targeted for curricular modification. The laptops are distributed to students during regular class and lab hours so that software training and in-class projects can be conducted. The targeted courses were scheduled so that the laptop cart would be available to all of the instructors/courses involved in the project.

The main software product that is being used for all of the targeted courses is ESRI's ArcGIS. gINT for ArcGIS, a geotechnical software for spatially relating borehole logs, was purchased for the Applied Soil Mechanics course, along with TransCad for the Transportation Systems Engineering course. The remaining programs that were required, CTPP 2000 and the Caliper Introductory Travel Demand Forecasting Workshop, were available free of charge from the Bureau of Transportation Statistics and the Caliper Corporation, respectively.

PROJECT IMPLEMENTATION

One of the main objectives in the Civil Engineering Foundation Sequence is to provide an educational environment where students can develop engineering problem solving skills and learn the basic concepts of design. Basic problem solving heuristics are implemented by student groups to define requirements, design, fabricate, and quantitatively test products or processes typical to civil engineering. These products are not "models," but rather they are pilot-scale designs. Each group's design product must satisfy a set of design and operational criteria and are evaluated based on a performance measurement. Success in the course is based on a technical presentation of the design and analysis of the product and its performance.

The implementation of the current project for the Department of Civil Engineering at The University of Memphis was designed to begin with design projects added or altered in scope to integrate GIS applications beginning with the introductory course in the freshman year of the program, which is the course largest enrollment in the program. The specific courses targeted with this project are listed below, along with a description of the selected curriculum changes to integrate the GIS-based design experience.

Freshman Year

CIVL 1101 Civil Engineering Measurements - The introductory project in this course is to survey a site and developing a basic geographic surface model. Historically, survey data has been collected and an elementary surface model developed by hand or with simple computational tools. The resulting surface model is then used as a basis for more sophisticated analysis the following semester. Although this is a small-scale project, the process is identical to that used in some civil engineering projects. The data will be collected using the hand-held Global Positioning System (GPS) units purchased through this project. A GIS will then be used to develop, analyze, store, manage, and display the geographic information obtained from the survey.

More importantly, beginning as freshmen, civil engineering students will learn to the work with the GIS and will realize the power of having a comprehensive source for geographic data within the department. Students and student groups across the curriculum can exchange information and share analyses through a common system. In addition, the GIS lab brings together students of all levels in a shared environment where advanced students can interact and mentor beginning students.

CIVL 1112 Civil Engineering Analysis - Based on data collected and developed in the first semester, student groups will design and analyze a rainfall runoff detention pond to meet a set of project criteria. The design will require the analysis of spatial data to estimate earth-work cost and detention pond volume. Analysis and visualization tools in the GIS will allow the evaluation of more sophisticated and realistic pond designs. In particular, the GIS will provide a visual platform for the assessment of both quantitative and qualitative aspects of alternative detention pond designs. In addition, the visualization capabili-ties of the GIS will enhance both intra- and inter-group communications and hopefully encourage students to seek more cost-efficient and comprehensive solutions to their design projects.

Sophomore Year

CIVL 2101 Civil Engineering Visualization - Students will learn how to integrate traditional CAD programs with information from a GIS. In addition, specialized CAD packages for civil engineering design are introduced in the course that will be facilitated by the integration of GIS information. Handheld GPS units will be used to collect data for use in the projects in this course.

CIVL 2107 Civil Engineering Computation - Students will take information from the GIS and utilize that information in the modeling of impacts of engineering design decisions. Simplified models of environments will be utilized to allow students to develop decision systems including technical as well as non-technical impacts. Handheld GPS units will also be used to collect data for use in the projects in this course.

Junior Year

CIVL 3103 Approximations and Uncertainty in Engineering - Several projects will be incorporated throughout the semester using the Census Transportation Planning Package (CTPP) 2000 provided free of charge through the Bureau of Transportation Statistics. This software allows manipulation of the vast Census database and analysis within a GIS environment. The data for the State of Tennessee will be used to create projects of interest to students that will demonstrate the relevance of statistical applications to civil engineering practice. Because this course is a

co-requisite to CIVL 3161, and a pre-requisite to other transportation electives, the CTPP 2000 software was selected to provide continuity among the related courses through projects based on transportation engineering applications.

CIVL 3140 Environmental Systems Engineering - Students must consider water needs, waste generation, and environmental impacts from the perspective of civil engineering design. These require the ability to consider community growth patterns, existing and proposed infrastructure, as well as costs for development decisions. A GIS will allow the course to have a visible framework to present all of these topics within.

CIVL 3161 Transportation Systems Engineering - More advanced uses of the CTPP 2000 will be incorporated into this course. The project developed for this course will also be used to demonstrate the links between CIVL 3103 and CIVL 3161. Transportation GIS Software (TransCad) will be introduced in CIVL 3161 so that students become familiar with its structure, and will learn to perform several tasks in relation to transportation system design. TransCad facilitates transportation system analysis, planning, and management. A demo version of this software is available free to students, and allows users to explore the functionality of the software with a provided data set. This software is widely used by transportation professionals and exposure to this program will markedly enhance students' preparedness for transportation engineering careers. An additional software package, Caliper Introductory Travel Demand Forecasting Workshop Software, available free to students through Caliper Corporation, will also be introduced. The GIS-based program will be used to enhance the trip generation section of the course.

Senior Year

CIVL 4151 Applied Soil Mechanics - GIS applications will be included in the subsurface exploration portion of this course. Specifically, one three hour lab session will be dedicated to the development of boring logs and GIS will be used to develop soil profiles for a given project site. The software gINT for ArcGIS will be used to incorporate soil boring and laboratory test data information into boring log format.

CIVL 4199 Civil Engineering Design - GIS applications will not be formally integrated into this course. However, students will have acquired the skills necessary to use GIS to facilitate their individual and group project designs that are the focus of the curriculum. Students will also have access to the laboratory facilities provided by the proposed project in order to develop their design solutions.

ASSESSMENT PLAN

The design of this project makes it possible to collect both formative and summative information, as the content will be interwoven throughout nine courses within the Civil Engineering Curriculum. Formative data collection will include student surveys, observation of instructional methodology, and subsequent modifications based on those findings, while summative data will be collected during the final required course for a degree in Civil Engineering.

In addition, the distribution of these courses through all concentration areas in Civil Engineering in both lower level and upper level undergraduate courses will allow a unique opportunity for longitudinal assessment. More specifically, the longitudinal study will be assessed through use of both descriptive and experimental techniques. Measurement instruments used to obtain descriptive information will include a combination of qualitative, quantitative, and mixed-method research strategies in order to enhance the reliability and validity of the data through multiple sources of data. Examples of the types of instruments used to obtain descriptive data include pre/post surveys, peer and instructor evaluation forms, and the integration of short-term instructional activities and/or tasks that take place at several points during each course in order to document levels of transfer, understanding, and application of specific skills presented in different contexts throughout the course.

Because the proposed study follows a particular set of required courses within a specific curriculum, it will be possible to combine data from descriptive techniques from course to course and year to year[25]. At the conclusion of the study, this data will be examined to identify any trends and/or areas of strengths and weaknesses associated with the program.

PROGRESS TO DATE

The GIS laboratory has been established, and all software has been obtained and installed. This portion of the project was just completed during the Fall 2007 semester, thus only a few GIS projects have been incorporated into the curriculum at this point. To date, the only curricular modifications that have occurred are those for CIVL 2101 and CIVL 3161, with the remaining courses modifications to be integrated in the Spring 2008 and Fall 2008 semesters. The first complete assessment of the modifications will be available after the Fall 2008 semester, although informal assessment of the CIVL 3161 and CIVL 2101 courses indicate the changes were well received, with students reporting that they felt more competent in the course topics because of the GIS projects, and had a better understanding of how the material covered might be applied in a real-world setting.

CONCLUSION

Technological knowledge, skills, and applications are important contributors to the academic success of all students, but for engineering students, these skills and strategies are critical components required for professional practice in the 21st century. In response to the ever-increasing technological advances, engineering educators face challenging instructional strategies of teaching the core content of traditional engineering pedagogy while integrating knowledge of current technological tools and applications used within professional practice without adding credit hours to existing programs. The goal of this project is to address the need for integration of technology, real-world problem solving strategies, and an understanding of the broad and complex nature of most civil engineering problems through the modification of undergraduate curriculum with GIS applications to demonstrate the variety of issues encountered in civil engineering practice.

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Stephanie Ivey

Dr. Stephanie Ivey is an Assistant Professor with the Department of Civil Engineering at the University of Memphis. She has been a program faculty for the Herff College of Engineering's targeted outreach program, Girls Experiencing Engineering, since its inception in 2004, and has also served as program faculty in other co-educational outreach programs. Dr. Ivey is the faculty advisor for the student chapter of the Institute of Transportation Engineers at the University, and serves as the Younger Member Chair for the West Tennessee Branch of the American Society of Civil Engineers. Dr. Ivey received the ASCE Outstanding faculty award for the 2005-2006 and 2006-2007 academic years from the University of Memphis ASCE student chapter, and the ASCE Tennessee Section Young Engineer award in 2007.

Paul Palazolo

Paul J. Palazolo is the Assistant Dean for the College of Engineering at the University of Memphis. He is also a member of the development and teaching team for the introductory sequence of classes in the Civil Engineering department. Dr. Palazolo is a registered engineering in the State of Tennessee and in actively involved in educational research in engineering. Dr. Palazolo received his B.S. and M.S. in Civil Engineering from Memphis State University and a Ph.D. from the Georgia Institute of Technology. He recently received the 2007 ASCE Tennessee Section Peter G. Hoadley Outstanding Engineering Educator award.

Charles Camp

Charles V. Camp is the Bobby Warton Professor of Civil Engineering at The University of Memphis. He received his B.S. and M.S. from Auburn University and his Ph.D. from Oklahoma State University. He is a member of the development and teaching team for the introductory sequence of courses in the Civil Engineering department in addition to teaching courses in structural engineering at both the undergraduate and graduate level.

Anna Lambert

Anna Lambert is currently a faculty member in the department of Civil Engineering at the University of Memphis and the direction of the Engineering Communication Center for the Herff College of Engineering at the University of Memphis. She is also a member of the development and teaching team for the Foundation sequence of courses in Civil Engineering. She advises the college on both communication and assessment issues in course development.

David Arellano
David Arellano has been an assistant professor of civil engineering at the University of Memphis since August 2005. Previously, he worked in private practice for nearly ten years for several geotechnical engineering consulting firms. In addition to private practice, he was an officer in the Corps of Engineers in the U.S. Army Reserve for nearly 23 years. He obtained both his undergraduate and graduate degrees from the University of Illinois in Champaign. Dr. Arellano is a licensed Professional Engineer in Illinois and Wisconsin.