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Internet-Based Interactive Construction Management Learning System

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Incorporation of classroom tasks that improve the abilities of students to manage the complex dynamics, pressures, and demands of construction sites is becoming critical to meet the demands of the construction industry. These goals are, however, difficult to incorporate using traditional educational tools. This paper describes the work being performed as part of a three-year project that has been funded by the National Science Foundation (NSF). The goal of the project is to enhance the undergraduate construction engineering and management education by incorporating practical content into the construction engineering and management curricula, thus bridging the gap between the classroom and the construction site. These enhancements are accomplished by developing: 1) an Internet-based Interactive Construction Management Learning System (ICMLS) and 2) an advising and mentorship program that enhances practitioner-involvement. ICMLS uses Internet-based interactive and adaptive learning environments to train students in the areas of construction methods, equipment and processes. This system is being developed using multimedia, Internet-based computing, databases, discrete-event simulation, and Virtual Reality Modeling Language (VRML).

Key Words: Construction, Education, Interactive Learning, Internet-Based Computing, Virtual Reality Modeling Language (VRML), Discrete Event Simulation

Introduction and Background

Construction is a very large and diverse business and is a significant employer, cash generator, and contributor to the economy. Growth and the replacement of people leaving the labor force will add more than 68,000 new positions for civil engineers by the year 2005, according to a recent forecast of employment trends (ASCE, 1996). Attracting talented high school graduates and imparting the best possible civil and construction engineering education is critical to the future of the U.S. construction industry.

In the early 1980’s, the construction industry faced increased national and international competition, stringent governmental regulations, and an environmentally conscious populace. The industry also encountered issues such as organized labor, challenges of new technologies and new materials, and construction of complex projects. These forces emphasized the value of strong engineering and management skills required for delivering high quality constructed facilities. That, in turn, added a new dimension to the profession and led to the evolution of a group of professionals among civil engineers who practice construction management.
As a direct response to the needs of the construction industry, universities around the nation started undergraduate and graduate curricula in civil and construction engineering that provide more emphasis on construction engineering and management (Oglesby, 1982 and Tatum, 1987).

Construction Education – Current Status

Over the past few years' national organizations such as American Society of Civil Engineers (ASCE), American Society of Engineering Education (ASEE), National Science Foundation (NSF), and National Research Council (NRC) have sponsored numerous studies to gauge the current status of undergraduate engineering education and to develop an agenda for improvement. These studies have identified a number of major issues such as: 1) faculty development; 2) practitioner involvement; 3) development of integrated curriculum; 4) focus on diversity; 5) new approaches to assessment of faculty, students, courses, and curricula; 6) broader and flexible curricula; and 7) utilization of active learning approaches (ASCE, 1995 and NSF, 1995). These initiatives have brought new impetus aimed at the continuous improvement of undergraduate engineering education.

Similar studies have also been undertaken on the civil and construction engineering education front. A study conducted by the Institution of Structural Engineers in the UK reveals that civil engineering education should include practicality and feel for construction engineering (Walker, 1981 and Shaw, 1981). In reality, many civil and construction undergraduate programs fail to provide students with an arena where they can acquire the skills and experience necessary to successful professional practice and on-site performance (Hadipriono and Sierakowski, 1986 and Fruchter, 1997)). Most civil engineers need to spend many years in the field in order to assimilate an adequate knowledge about actual construction performance. Therefore, it is imperative for civil engineering (and construction engineering and management) educators to promote these education enhancement factors to undergraduate students in the classroom (Hadipriono, 1985;Hadipriono and Larew, 1985; and Echeverry, 1996).

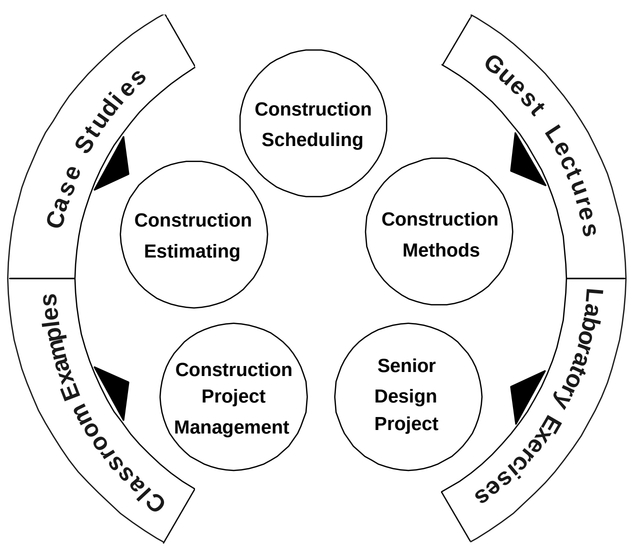

Figure 1. Current Construction Engineering and Management Education.

Figure 1 explains the status of the current civil and construction engineering and management curricula. Students complete key courses such as construction materials and methods, estimating, scheduling, and project management before undertaking the senior design project. Instructors use case studies, classroom examples, guest lectures, and laboratory exercises to explain the application of classroom knowledge in solving real problems. However, the current approach is often inadequate in preparing students for the on-site construction processes. This is evident from the sudden “jump” the students experience when starting their senior design project. The reasons for this “jump” are: 1) lack of adequate experience in the dynamics and complexity of the construction site; and 2) lack of guidance and interaction with construction experts. The senior design project—normally one semester in duration—does not completely accomplish its objective due to this missing link in the current curriculum.

It is clear from these studies that the current civil and construction engineering curricula are often inadequate in preparing students for the complex process of construction. Weaknesses include a fragmented curriculum that does not permit the inclusion of issues of importance to construction, the limited access to construction practitioners and hands-on experience, and limited use of advanced computing tools to improve student learning.

Problem Statement

The traditional teaching methods are often not fully capable of providing students with all the skills necessary to solve the real-world problems encountered in construction (AbouRizk and Sawhney, 1994) or conveying complex engineering knowledge effectively. The instruction methods used to convey this engineering knowledge in the majority of construction engineering and management curricula rely, for the most part, on traditional methods such as exposing students to applied science courses. Also, curricula often convey this knowledge in fragments in a series of courses (Fruchter, 1996 and Fruchter, 1997) and do not provide enough opportunities for students to interact with construction professionals or to pool the knowledge acquired in several courses to solve real-world problems.

Ideally, visits to construction sites or site training would constantly complement the more conventional classroom instructional tools. However, there are various complicating issues that make it impossible to rely on the sites. Foremost, the instructor cannot control the availability of a project at the necessary stage of completion. Also, visits of larger groups to construction sites may not be welcome, involve risk, and are unpractical (Echeverry, 1996). Finally, the high cost of site training is a further impediment to its extensive use for construction education (AbouRizk, 1993 and AbouRizk and Sawhney, 1994). General computing and information technologies, and simulation in particular, have the potential to complement construction engineering and management education. The authors, motivated by this, have undertaken this research project to address the above-mentioned issues through the development of an integrated educational framework that will expose the civil and construction engineering students to the complexities of the construction site.

State of the Art

Numerous innovative tools have been used to enhance the learning of civil and construction engineering students. Some common examples are site-visits, use of construction site-videos, computer simulation and gaming, internship, and summer training.

The idea of construction games can be traced back to Au and Parti (1969) who suggested that computerized heuristic games could be used for the education of engineers and planners engaged in the construction industry. Scott and Cullingford (1973) described a scheduling game for construction industry training. Halpin (1976) presented a model for the project gaming system CONSTRUCTO that allows students to plan, monitor, and control hypothetical projects. Harris and Evans (1977) developed a road construction simulation game for site managers focussing on the planning and control of linear construction projects. Herbsman (1986) explained the use of civil engineering project management games at the University of Florida where each player was required to participate in the design and execution phase of an assigned actual project being constructed near the university. Rounds et al. (1986) described a construction game that simulates the progress and project reporting structure of an industrial construction project. Dudziak and Hendrickson (1988) developed a simulation game for contract negotiations. Vehosky and Egbers (1991) explained the development and use of a game for simulation of management of a design and construction project. AbouRizk (1993) and AbouRizk and Sawhney (1994) described the development and deployment of a construction bidding game that provides the undergraduate students of civil and construction engineering a thorough understanding of the components and methods of construction bidding. Fruchter and Krawinkler (1995) described the development and testing of a new and innovative computer integrated Architecture Engineering Construction (AEC) teaching environment.

From the above summary it can be observed that a number active learning systems aimed at training students in different aspects of construction management, have been designed and implemented. Most of the systems mentioned above are either manual or have been developed with limited use of advanced computing tools. They are not geared towards the dissemination of knowledge related to construction processes, methods, equipment, and decision-making factors related to site execution of construction processes. Active participation of construction practitioners is also not utilized in these systems. This research project derives its motivation from the systems described above and demonstrates the effectiveness of utilizing active learning concepts to enhance classroom instruction.

Overview of the Research Project

The research project is based on the development of an Internet-based Construction Management Learning System (ICMLS) that utilizes: 1) active learning approaches to bridge the gap between the classroom and the actual construction site; 2) advanced Internet-based computing technologies to bring the complexities of the construction site to the classroom; and 3) knowledge and expertise of construction professionals through an advising and mentorship program. Figure 2 depicts ICMLS and the mentorship program in the context of construction engineering and management education. The system is used as an instructional tool for the key courses identified in the figure to introduce practical construction management concepts. The project advisory committee consisting of regional construction practitioners is guiding the development of the ICMLS. During the testing and final utilization of the system members of the advisory committee will act as student mentors. This strategy helps the students gain: 1) adequate experience in the dynamics and complexity of the construction site; and 2) guidance and interaction with construction experts.

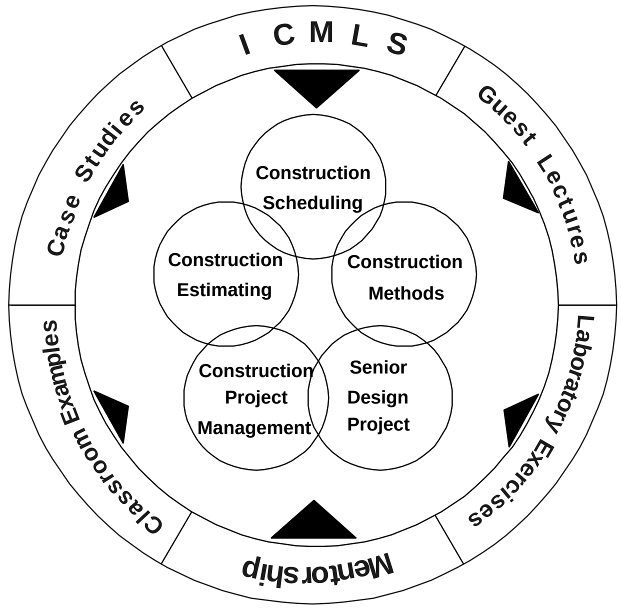

Figure 2. ICMLS and the Mentorship Program in Construction Engineering and Management Education.

What is ICMLS?

The Internet-based Interactive Construction Management Learning System (ICMLS) is a simple tool that students can utilize to gain practical knowledge of construction equipment and construction processes. The key features of the ICMLS are its use of the Internet as its launching medium, and its use of multimedia databases, hypertext, 3-D modeling, and simulation to provide students with an interesting and realistic view of the selected construction processes and construction equipment. ICMLS uses an interactive and adaptive learning environment to improve students' learning in the area of planning of construction processes and equipment. The system is process-oriented and mimics the challenges faced by a construction manager on a real life construction project. It allows students to apply their knowledge of construction materials and methods, estimating, scheduling, resource allocation and utilization, fleet size determination, productivity and cost calculations, and decision-making in relation to construction processes in a holistic, non-fragmented way. Discrete event simulation, 3D modeling, and mentoring by construction professionals bring practical content to the curriculum.

Challenges Addressed by ICMLS

The challenges of education/instruction are manifold and range from issues related to the enhancement of the learning abilities of students to curricula integration and the inclusion in the curricula of hands-on, real-world experiences. The following paragraphs describe some of these challenges as well as some potential solutions to shortcomings:

1. The improvement of the learning abilities of students: Generally, one of the most important findings of research efforts directed at identifying features that enhance student learning, is that students learn more effectively and permanently when they can actively participate in the learning process (Chi et al., 1989). It is thus important to provide possibilities for the students to actively use and explore the new concepts as they learn them. Computing technologies such as course material on floppy disks or CD-ROM and the Internet can be helpful in complementing the instruction. Further, computerized (simulation) games that can respond to the user's actions allow for a learning experience to take place (AbouRizk and Sawhney, 1994).
2. Knowledge fragmentation: Current curricula do not give students a holistic view of their field of study. A typical undergraduate program in civil engineering includes curricular components such as mathematics and basic sciences, humanities and social sciences, engineering sciences, civil engineering design, and civil engineering core courses (ABET, 1993). The conventional civil engineering curriculum, implemented at most U.S. Universities, focuses on unlinked and independent core and support courses that convey knowledge in fragments. Often students neither retain nor are able to utilize knowledge acquired in previous courses (Bertz and Baker, 1996). To address these shortcomings, there is the need to develop curricular instruments that will require students to pool their knowledge to solve authentic real-world problems. Project-based learning, where learning evolves around real-world projects that span various disciplines, can also be implemented to address these shortcomings.
3. Providing hands-on experience: The incorporation of a practical element in construction engineering and management is of foremost importance. However, as discussed above, several factors complicate or even prevent the use of extensive site training. Computer-based games that simulate the environment of construction, with all its complex and dynamic relationships between different factors, can, however, bridge the gap between the classroom and the construction site by allowing the students to take actions and learn from the responses to these actions.

The research being conducted by the authors addresses these issues and incorporates strategies to meet the challenges identified above.

Internal Components of ICMLS

The internal structure of ICMLS is shown in Figure 3. Internally, ICMLS consists of a number of components that are described in the following sub-sections.

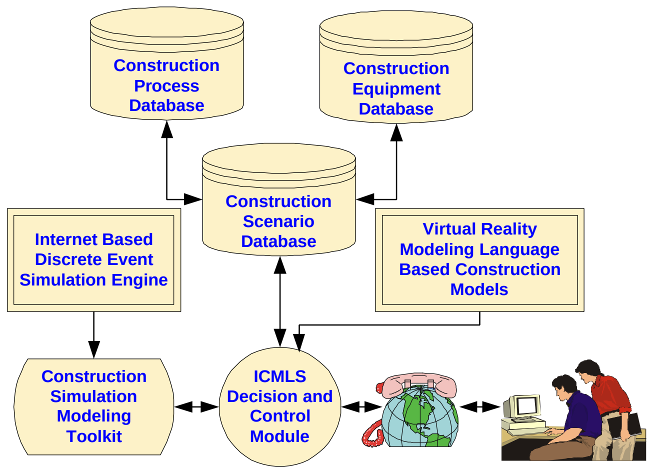

Figure 3. Internal Components of ICMLS.

Construction Equipment Database

This component contains information pertaining to equipment specifications, productivity, operation, use, and manufacturers. The construction equipment has been divided into eleven categories with approximately 70 different pieces of equipment being identified in those categories. Over 200 construction equipment manufacturers have been contacted to collect information. Figure 4 shows the actual screen of ICMLS from where construction equipment information can be accessed by the student.

Figure 4. Construction Equipment Database.

Construction Process Database

This repository contains a number of construction processes from residential, building, heavy engineering, and industrial construction. Visual as well as textual explanations of the processes are supplemented with multimedia elements. The construction process database has been divided into two broad categories that include building construction and heavy construction. Figure 5 shows the construction process database screen in ICMLS.

Figure 5. Construction Process Database.

Construction Scenario Database

The construction scenario database contains a number of real world scenarios that are used in the interactive mode of ICMLS. Figure 6 shows a sample from the construction scenario database. This database is internally linked to the construction process database so as to synchronize the two databases. Students use this component of ICMLS to study the interactions between construction equipment and construction activities in a construction process. The interactivity in this component is further enhanced by the Virtual Reality Modeling Language (VRML)-Based Construction Models and Internet-Based Discrete Event Simulation component of ICMLS.

Figure 6. Construction Scenario Database.

Virtual Reality Modeling Language-Based Construction Models

The Virtual Reality Modeling Language (VRML) is a three-dimensional (3-D) modeling language that can be used for describing 3-D shapes and scenery (also called a virtual world) on the World Wide Web (WWW) (Ames et al., 1996 and Hartman et al., 1996). VRML can be defined as a 3-D analogue to Hypertext Markup Language (Lea et al., 1996).

VRML files are text files that contain information regarding the objects and linkages between the objects in a virtual world. It can be applied to a number of areas including web-based entertainment, 3-D user interfaces to remote web resources, 3-D collaborative environments, and interactive simulations for education, virtual museums, virtual retail spaces, and more. The ability to animate, play sound and video within the virtual world allows users to interact with the virtual world. The control and enhancement of the virtual world with scripts allows the development of dynamic and sensory-rich virtual environments on the Internet (Cosmo Software, 1997). These features of VRML can be beneficially utilized to build teaching aids that supplement classroom instruction. As part of ICMLS, the authors are using VRML to develop these innovative and accessible teaching aids. The authors have developed interactive 3-D simulations that are being used to teach construction processes. Figure 7 and 8 show an Internet based 3-D model of steps involved in residential construction that have been implemented as part of ICMLS. Students can access this 3-D model through a web browser that is equipped with a VRML plug-in.

Figure 7. VRML-based Animation of Residential Construction.

Figure 8. VRML-based Animation of Residential Construction.

Internet-Based Discrete Event Simulation

One of the key components that adds interactivity to ICMLS is discrete-event simulation. Traditionally, simulation has been defined as a tool that can be used to mimic reality and provide responses of a system under consideration to external and internal factors. Simulation has been applied in the design and analysis of construction processes by researchers and by some large construction organizations (Halpin and Riggs, 1992). In addition to industrial uses, simulation can also be used for educational purposes, especially for civil and construction engineering education. This is based on the hypothesis that "simulated environments" can act as excellent catalysts in the learning process. In a recent study, Suda (1993) reported that "simulation can be a powerful trigger to learning of project management principles."

With the advancement of computing technology and widespread adoption of the Java programming language as a standard for Internet-based computing, application of simulation in education is becoming a reality. Tools are now available to allow development of "simulated environments" that are accessible to students over the Internet. In ICMLS, the authors have utilized Java-based simulation to allow students to interactively manage construction processes in a simulated environment. This development is based on the Silk? environment (Healy and Kilgore, 1997 and Healy and Kilgore, 1998).

The Java-based simulation component of ICMLS allows users to model common construction processes. Students select a problem scenario from an existing list displayed by the system. For example, students can select a scenario in which they are required to supervise the moving of 234,000 units of earth for a canal project. Students can then utilize Java-based simulation to study the earthmoving process. They can use the session to: 1) select a fleet of equipment—in this case front end loaders and dump trucks—to accomplish the earthmoving; 2) determine total productivity; 3) determine total project cost; and 4) determine total duration of the earthmoving process. Figure 9 shows a sample screen of ICMLS for the simulation of the earthmoving process.

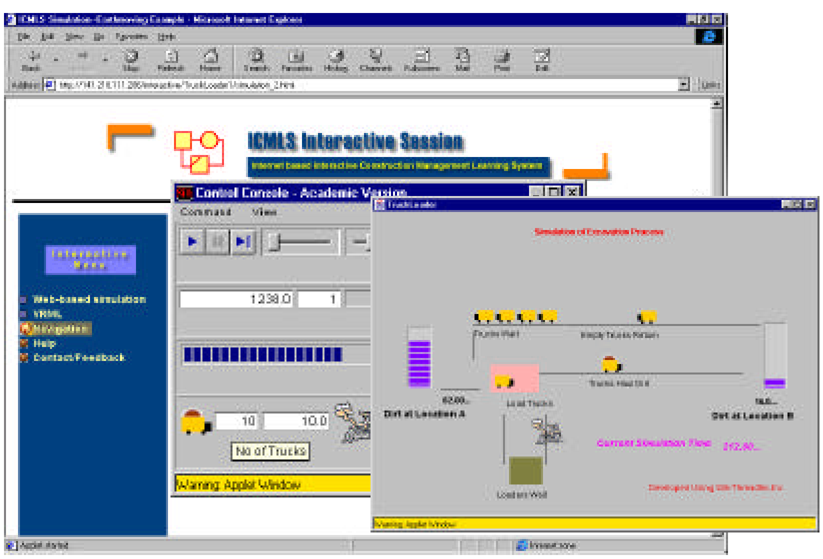

Figure 9. ICMLS Simulation.

Student Interaction with ICMLS

The critical factor in the success of the ICMLS is the clear identification of student interaction with the system. The system is design for utilization in the construction materials and methods, construction estimating, construction scheduling, and construction project management courses. The students utilize the system in consultation with an industry mentor. In addition, the system can be utilized in other civil engineering courses, introductory pre-engineering courses, and for demonstrations to prospective transfer students. Figure 10 shows the student interaction process.

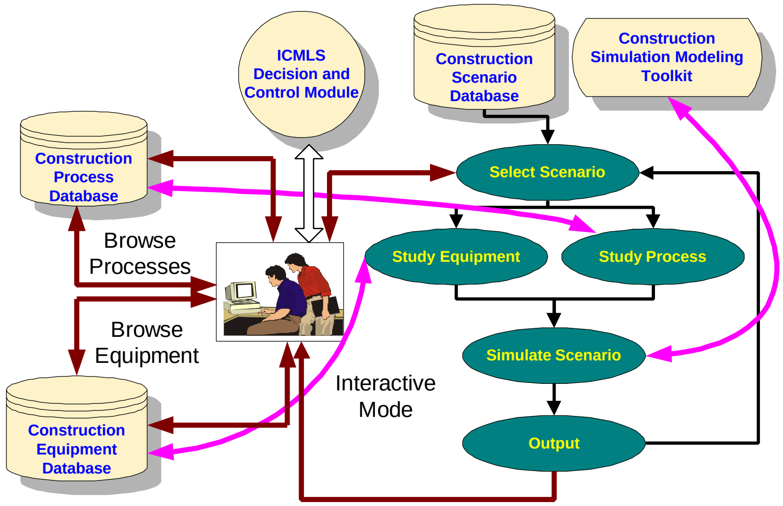

Figure 10. Student Interaction Process.

The students can utilize the Interactive Learning System in the following three modes:

1. In the first mode, a student can browse through the "electronic" database of construction processes. This gives students an idea of construction site operations. For example, a student can select the slurry wall construction process and obtain textual, graphical, and multimedia explanation for the process. In this mode, the student learns about the construction technology, construction method, equipment usage, material usage, and underlying work tasks and their sequencing.
2. In the second mode, a student can select the "electronic" database option and browse through the available construction equipment. For example, the student can select a vibratory pile driver and obtain information about the general description of the equipment and performance factors such as amplitude, eccentric moment, frequency, vibrating weight, and non-vibrating weight of the vibratory pile driver. This database also utilizes text, graphics, and multimedia to provide the students with the information related to equipment characteristics, equipment usage, and technology involved.
3. In the third mode, the system is used as an interactive simulation and gaming environment that presents students with real life construction problem scenarios and allows them to develop a solution, implement the solution, visually study the response of the system to the solution, and then iteratively improve the solution. This allows students to learn subtle and complex interactions between construction costs and time. The actual solution is presented to the system by the development of a simulation model. The students

formulate the following inputs: 1) study the underlying construction method and technology; 2) develop an appropriate simulation model; 3) select equipment and allocate them to the developed simulation model; and 4) select duration for the work tasks identified as part of the simulation model.

Integration of ICMLS into the Curriculum

Successful utilization of ICMLS requires effective strategies to integrate it into the curriculum of the following disciplines:

1. Civil Engineering—both at the lower and upper level of the undergraduate curriculum
2. Construction Engineering and Management—both at the lower and upper level of the undergraduate curriculum
3. Two-year Transfer Degree Programs in civil and construction engineering

Table 1 provides a listing of student experiments and projects that result from the usage of ICMLS. ICMLS is scheduled to be beta-tested in some of the courses listed below, starting in the fall of 2001.

Table
Interactive Learning System-based Student Experiments and Projects

Course Description	**Student Activity**	**Faculty Advisor**	**Industry Mentor**
Introduction to Construction	Use of Interactive Learning System in the demonstration and browse mode	Required	Optional
Introduction to Engineering Design	Demonstration of the Interactive Learning System	Required	Optional
Construction Materials and Methods	Use of Interactive Learning System in the interactive mode	Required	Optional
Construction Scheduling	Use of Interactive Learning System in the interactive mode	Required	Optional
Construction Estimating and Bidding	Use of Interactive Learning System in the interactive mode	Required	Optional
Construction Project Management	Use of Interactive Learning System in the interactive mode	Required	Required
Senior Design Project	Use of Interactive Learning System in the interactive mode	Required	Required

Conclusions

The authors envision that the successful completion of this project will provide an instructional tool that clearly caters to the needs of civil engineering education in general and construction engineering and management education in particular. A number of benefits arise from the development of ICMLS. These include graduates that are better prepared to manage the complex dynamics, pressures, and demands of construction sites. The availability of “job-ready” graduates is becoming crucial in trying to meet the demands of the construction industry today. The enhanced practitioner involvement and construction industry input, increases practical content and can provide students with increased familiarity with the construction industry. The improved recruitment, retention, and program completion for the construction engineering and management program are of benefit to the university. As can be seen, ultimately all parties involved, universities, students, and the construction industry, can benefit from ICMLS. The university will generate more importance and interest as an educational institution through improved recruitment and better graduates, while the students will benefit from a better education that will ultimately also benefit the construction industry.

Acknowledgements

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