

## Early Experimentation with Civil Engineering Materials

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### Abstract

A new project-based teaching method emphasizing laboratory experimentation is being used at Lawrence Technological University. It has excited and energized the students about civil engineering applications. Engineering concepts are introduced early in the students' academic careers using civil engineering materials. Laboratory activities related to a Civil Engineering Materials course are being used for outreach, recruitment, and an intensive laboratory experience. A departmental effort has included supporting an outreach program and expanding a freshman CE Materials course. This new teaching method has affected and complemented university recruitment and retention efforts. The course introduces incoming students to engineering analysis and the basic elements of design. CE1413 has a strong emphasis placed on practical applications for engineering design including financial considerations; engineering behavior (such as strength, thermal response, physical conditions); experimental techniques; testing specifications; comparison to field behavior; sustainable development; and analysis techniques. Students are responsible for specifying appropriate testing conditions and variables for individual experimental test programs of basic civil engineering material behavior. They relate the testing program to a practical example of civil engineering design. A wide variety of innovative experimental programs have been conducted ranging from analyzing bond strength of composite and conventional concrete reinforcing materials to comparing wood truss connection assemblies.

### Introduction

A project-based teaching method has been introduced at Lawrence Technological University for a freshman Civil Engineering Materials course. CE1413, Civil Engineering Materials, has an emphasis on experiments to analyze physical behavior of materials. A hands-on laboratory session introduces students to experimental techniques and to the range of materials available to today's civil engineering industry. A primary component of CE1413 is an individual experimental test program designed by the students. The project has been successful in capturing student interest in civil engineering and has helped reach department goals associated with outreach education, recruitment, and retention. The content of CE1413 and the experimental project is described. How the new course format fits into the entire curriculum is discussed. The manner in which the project interfaces industry and research is detailed. The benefits of this project to the department are identified. Student assessment of the program and future directions for the project are briefly presented.

## Course Description

The topics in this course include soil and aggregates as engineering materials; concrete mix design and mechanical behavior of concrete; reinforcing and admixtures for concrete; timber and wood systems; mechanical behavior, microstructure, and manufacturing of metals; manufacturing and mechanical behavior of plastics; applications of geosynthetics; asphalt cements; and composite materials. The course was recently changed from 2 credits to 3 credits to allow for expanding the laboratory component of the course. The total laboratory hours in the course were not changed (one 2-hour session each week). However, with the additional class time, better preparation is possible making the laboratory sessions more efficient and productive. The additional credit of CE1413 has replaced a 1 credit Mechanics of Materials laboratory requirement. As a provision to the replacement of this credit hour, mechanical aspects of material behavior are emphasized in CE Materials. Hardness, fatigue, stress relaxation, creep, and composite behavior are examined through experiments in this course.

Experiments are conducted on a weekly basis and engineering reports are prepared by the students. The laboratory reports often combine numerous weeks of experimental testing. The laboratory assignments are presented as hypothetical requests to a materials testing firm. The students are required to reply to the request in business letter format with an engineering report attached as an appendix. This format emphasizes the importance of quality written communication skills early in the students' academic careers.

## Placement in Curriculum

The new 3 credit format for CE1413 represents changes made to improve continuity of the civil engineering curriculum. This course builds on basic mathematics and computer skills and provides practical applications for these concepts and skills. The course was expanded from 2 to 3 credits to maximize the impact of a freshman level departmental course. This course promotes increased interaction among the freshman students and the civil engineering faculty and staff. The extra involvement by the freshman has been observed in other departmental functions such as ASCE student membership.

CE1413 indirectly introduces many of the specialties within civil engineering. This class provides the students with a broad overview of the profession they are entering. Compared to the typical third year placement of a CE Materials course, this schedule allows students to understand the physical behavior of materials as a preface to understanding the theory for the observed behavior. Other courses depend on CE 1413 to provide students some familiarity with basic concepts of engineering design such as stress, strain, durability, creep, failure, and factor of safety. Many courses within the curriculum benefit from the students' early exposure to such concepts.

The course prepares students to become proficient in analysis tools such as spreadsheets and graphing and introduces the concepts of experimental testing, data acquisition, and design of experiments. Most importantly, this course provides students with a sense of engineering judgment. The course introduces incoming students to engineering analysis and the basic elements of design. The hands-on laboratory experience provides students with a physical

representation of civil engineering behavior that they can use to define their personal engineering intuition and to approach their entire civil engineering coursework sequence.

### Project Description

The new project, introduced in 1997, is an open-ended experimental test program aimed at expanding the students' appreciation for civil engineering applications and aspects of successful design. Students are responsible for specifying appropriate testing conditions and variables for individual experimental test programs of basic civil engineering material behavior. CE1413 has a strong emphasis placed on practical applications of engineering design including financial considerations; engineering behavior (such as strength, thermal response, physical conditions); testing specifications; comparison to field behavior; sustainable development; and analysis techniques. This project prepares students to critically analyze experimental data related to engineering behavior of CE materials. A valuable perspective is gained by the students in analyzing data from the test programs. Civil engineering materials are often inherently variable and some scatter in data can be expected. Allowing the students to sort out reasons for scatter in the test data and the significance on the test results is a great learning experience.

A total of about 3 laboratory sessions are devoted to preparation, experimentation, and oral presentations of the results related to the experimental test projects. The class time devoted to the project is spread out over many weeks, so that the normal laboratory schedule for the class is not disrupted. Much of the work associated with test specimen preparation, conditioning, and actual testing is conducted outside of the scheduled class time. The cost of offering this project is minimal to the department. Aside from an increased demand on departmental equipment (and the department technician) for a few weeks during the semester, no additional budget has been required to include the project in the course. Denton<sup>1</sup> indicated that a lack of funding can be taken as an opportunity to focus efforts and pursue new directions in engineering education. Butterfield<sup>2</sup> and Petroski<sup>3</sup> also demonstrate benefits of teaching design without a cost increase. They have had success using very simple equipment (building blocks and paper clips) to present the process and importance of design. The CE1413 project uses more complex equipment, but encourages students to acquire materials necessary for their individual test program. To date, no financial difficulties have been encountered in offering this test program as part of the course.

Depending on the size of the class and the complexity of the materials projects chosen, the project is assigned either in teams or individually. Typically within a class, both individual and team efforts are represented. The team approach has been particularly beneficial to the freshman students. Others have reported success in design-oriented freshmen team learning experiences<sup>4</sup>. The importance of including design throughout the curriculum has been clearly identified<sup>5</sup>. The component of design associated with the CE1413 project is directed towards formulation of a problem and following through with an experimental test program of material behavior. Proper design of an experiment is emphasized in the course. Students are required to identify key variables in the problem and design a testing program with practical limitations of the variables in mind. The students are required to relate their test program and selection of experimental variables to practical civil engineering design applications.

The projects conducted so far can be identified as one of four main categories of testing programs: fundamental material behavior, optimizing engineering products for economy, sustainable infrastructure design practices, and interfacing with research projects at Lawrence Tech University. Examples of project topics, with the variables of the testing program identified, are presented in Table 1. The topics are arranged by category of testing program. The projects associated with fundamental material behavior pertain to materials and mechanics topics (Table 1 A). Cost and efficiency are emphasized in the projects as is shown in Table 1 B. Sustainable engineering design, that which enables function today without compromising the earth's resources for future generations, is promoted in the class. A number of projects have been conducted that assess sustainable development through the reuse of waste products in functional civil engineering design applications (Table 1 C). Finally, interaction with ongoing research at Lawrence Tech University has taken place on a number of projects (Table 1D). Current research projects at Lawrence Tech relate to composite reinforced concrete bridges and instrumentation of landfills.

Table 1 (A): Fundamental Material Behavior

Project Topic	Variable in Testing Program
Creep deformation of geomembranes at various temperatures	Temperature: freezer, oven, ambient
Compressive strength of wood as a function of moisture content	Moisture content: soaked and oven dried samples
Structural capacity of pine vs. oak specimens	Species of wood
Effect of water quality on compressive strength of concrete	Quality of mixing water
Corrosion of structural steel	Corrosion time and chemical solutions

Table 1 (B): Optimizing Engineering Products for Economy

Project Topic	Variable in Testing Program
Flexural response of wood beams	Composite wood I-beams vs. similar sized sections of lumber
Optimizing rodding of concrete cylinders	Number of blows per layer in preparing cylinders
Hydraulic conductivity of sand as a function of clay content	Clay content
Comparison of wood truss connections	Gusset plate vs. bolt assembly

Table 1 (C): Sustainable Infrastructure Design Practices

Project Topic	Variable in Testing Program
Assessment of soil stabilization using waste products	Percentage addition of fly ash and silica fume
Use of waste plastics as an additive/replacement for aggregate in concrete	Percentage of waste plastic additive

Table 1 (D): Interface with Research Projects at Lawrence Tech

Project Topic	Variable in Testing Program
Comparison of tensile strength of reinforcing materials for concrete	Carbon fiber reinforced plastic vs. structural steel
Pullout bond strength of various concrete reinforcing materials	Carbon fiber reinforced plastic vs. structural steel
Effect of metal types on thermocouple response and behavior	Thermocouple type

#### Benefits to the Department

One objective of adding a credit to the CE Materials course was to increase departmental credit-hours early in the curriculum. Early exposure to the civil engineering subject matter is linked to retention trends. This course has captured students' interest in civil engineering. While current enrollment trends in the College of Engineering at Lawrence Tech are declining, the civil engineering enrollment has increased about five percent a year for the past few years.

In addition, increased membership by freshman and sophomores in the ASCE student chapter has been observed since this project was introduced. The CE Materials course has been scheduled for the hour directly preceding the monthly student chapter meeting. This schedule has simplified recruitment efforts for ASCE membership of underclassmen. Attendance at the meetings has increased due to the convenience of the schedule. Interaction has increased among upper level students and the incoming students. The benefit of this interaction is much broader than a larger membership of the ASCE student chapter. Some of the most effective learning takes place among students alone. The upperclassmen have been impressed at the caliber of the individual projects of CE Materials. Much interaction has taken place regarding the planning of experimental test programs and the significance of the results.

Departmental recruitment efforts have also been affected by the CE Materials experiments. Lawrence Technological University's ASCE Student Chapter has developed a strong network of K-12 outreach programs in the Detroit-Metro Area. The content of the outreach programs differs depending on the age of the students and the timeframe associated with the activity. Outreach programs to date have included various structural competitions (spaghetti-marshmallow structures for elementary schools, toothpick bridges for middle schools, and dowel-string suspension bridges for high schools). Other outreach activities have included

aluminum foil boat design for young students and mixing and testing concrete for older students. The concrete mixing is conducted at the outreach school and the class is invited to Lawrence Tech to test their concrete cylinders after a curing period. Part of the visit to the campus includes a tour of the civil engineering laboratory facilities. The younger students of CE1413 are strongly encouraged to lead the organization and delivery of the outreach programs. This effort has been successful as some of the students have even used their experiments from class as demonstrations for the outreach programs.

The presence of civil engineering at the annual Lawrence Tech University Open House has increased substantially since the introduction of the CE Materials experimental projects. An entire classroom is devoted to presentation of the projects from CE1413. The students are responsible for preparing a poster describing their test and are encouraged to attend the Open House to describe the projects to visitors to the university. The Open House weekend represents a substantial recruitment effort for the entire university. Presentation of the projects has helped better define civil engineering to the public and in some cases affected decisions of potential incoming students. The inquisitive high school students have been impressed at the level of testing conducted by first year college students.

#### Interface with Industry and Research

The project has resulted in an increased interaction with the construction industry in the Detroit-Metro Area and has increased student awareness of civil engineering research at Lawrence Tech. The student population at Lawrence Technological University has been particularly receptive to this project. Many of Lawrence Tech’s students are working students (including a separate evening program) and undergraduate research is more prominent at Lawrence Tech than at many universities. Both working students and undergraduate research assistants are helpful to this project. Material donations and laboratory facilities have been provided by a wide variety of companies. Examples of industrial contributions are provided in Table 2.

Table 2. Benefits of Interface with Industry

Project Topic	Industrial Contribution
Composite wood beams	Lumber donated
Tension tests on carbon fiber reinforced plastic	Materials donated
Fiber reinforced concrete mixtures	Polymer and steel fibers donated
Soil stabilization techniques	Clay samples, fly-ash, and silica fume donated
Wood connection assemblies	Construction facilities and materials provided
Modification to concrete mix design	Concrete cylinders from construction project and testing facilities provided

Another aspect of interaction with industry is the employment of students. CE 1413, particularly the experimental project, can have a substantial impact on future employment opportunities for the students. The course gives the students particular skills that are valuable for pursuing summer employment positions in civil engineering. Students with basic skills in Atterberg limits testing of soils, slump testing of fresh concrete, and compression testing of concrete cylinders are continually being recruited for summer employment opportunities. Advanced skills associated with data acquisition and analysis techniques related to the project are beneficial to the employment-seeking students. Considering a broader perspective, the course exposes students to aspects of many of the disciplines within civil engineering. This early exposure can provide inspiration to specialize in an area and affect long-term career choices.

A well developed undergraduate research program exists at Lawrence Tech. Numerous research projects funded by the National Science Foundation are currently underway in the Civil Engineering Department. Interfacing this research with the class projects has been effective. Including the research in the classroom has promoted the success of the undergraduate research efforts. Research employment positions are effectively advertised by inclusion in the class project. In addition, from a faculty perspective, observing the students plan and conduct an experimental test program is an excellent way of choosing potential research assistants.

#### Assessment of the Project

Student reviews of the projects have generally been favorable. A number of student comments related to evaluation of the project are shown below.

- “The individual project is valuable because it gives the students an opportunity to do a project which can relate to any aspect of civil engineering that they choose. This allows the students to take a closer look at different types of engineering problems and help them to choose an emphasis which they may want to have for their careers.”
- “Experimentation is the backbone to any kind of engineering. Having the ability to do this in a course shows that the school (through you) want to help the field.”
- “The project allows the entire class to see more advanced testing on a particular material (i.e. wood, concrete, steel, etc.). I believe the project should be repeated in coming semesters so the future classes can see what happens to materials when you add a new variable to the standard testing previously done in lab. The project enhances the learning experience on CE Materials. There was also enough class time to prepare for the project.”
- “The design project is quite beneficial and I feel an important assignment within the curriculum of this course. Not only does it present an opportunity for students to experiment with various types of materials in order to complete the assignment.

It also assists them in drawing correlations from the research aspect to the real-world application. Inclusion of this research is a good starting block for students to design a test and work through aspects of the researching experimentation and conclusion of the testing.”

### Future Direction for Project

Due to the success of the individual experimental project, it is intended to keep this a part of the CE Materials course in future semesters. Plans to expand the experimental program are under development. The future direction of the project is to incorporate field work or field analysis into each project. This will increase the interface with industry and real world engineering problems. If a field component is included as part of the project, more class time would have to be devoted to the individual projects for proper planning and implementation of the work. The current schedule would have to be modified to reduce emphasis on other laboratory testing. It is planned to expand assessment of the program to include industrial partners and contributors in addition to the student evaluations. Also, an assessment of the quality of team work will be conducted, similar to a format proposed by Lewis et al.<sup>6</sup>.

### Conclusions

A new project-based teaching method has been introduced at Lawrence Technological University. The primary benefits of this method to the students are threefold. First, this method increases the level of interest and awareness of civil engineering within the incoming student group. Second, this method allows the students to be exposed to the basics of engineering mechanics before taking the calculus-based mechanics courses. Finally, the experience provides the students with an appreciation for engineering experimentation and an introduction to the concept of engineering judgment. From the department’s perspective, this project has interfaced well with outreach, recruitment, and retention efforts.

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