A New Approach to Undergraduate Structural Engineering Laboratory Instruction

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ABSTRACT: The way engineering is practiced today is very different from a decade ago. Technological advances and improved computing capabilities have changed the way civil engineers design, construct, and inspect engineered systems. The increased use of computer-aided design software and the shift towards the use of sensors and non-destructive testing have greatly impacted the profession. Yet, the undergraduate educational curriculum has remained virtually unchanged. By introducing these tools and practices, today's bachelor's level engineer will be better equipped and trained for a seamless transition into tomorrow's world.

The Structural Engineering Instrumentation and Measurements (SEIM) Laboratory at the Department of Civil and Environmental Engineering at the University of Rhode Island is designed to provide learning opportunities in a range of structural instrumentation topics. The Laboratory builds on accepted methods of instruction by employing a progressive learning approach, where successive lab modules increase in complexity. More significantly, the SEIM model promotes intellectual freedom and agility by allowing students to ***design their own experiments.*** In this manner, students are challenged to clearly define an engineering problem, effectively collaborate and communicate with group members, creatively outline several possible testing approaches, convincingly formulate arguments, and productively deal with diverse perspectives within a group.

INTRODUCTION

It is a widely recognized notion that students learn best by doing. In fact, the National Survey of Student Engagement (NSSE), a leading authority dedicated to improving undergraduate education, reports that students who engage more frequently in "deep" learning activities report greater educational and personal gains [1]. "Deep" learning includes activities that integrate learned theory into meaningful applications, ask students to explore their learning experiences, and include more in-depth thought. Yet, it is also reported that engineering students scored the lowest on the "deep" learning scale primarily due to low integrative and reflective scores.

Many others have reported on successful engineering education initiatives including opportunities for creative thinking, active learning, and increased awareness and participation with the professional community [2-4]. These studies all agree that the educational framework should focus on integration of knowledge, teamwork, and improved communication skills while maintaining strong analytical and technical skills.

Although proficiency within the discipline is desired, with a more global society, today's practicing engineers are also required to become less bounded by their traditional area of study [5]. Companies are seeking engineers that are critical thinkers with the capacity to recognize all aspects of a project and integrate knowledge from several sources. As a result, educational communities that encourage "connected learning" and provide opportunities for exploring relations across disciplines and beyond the classroom are encouraged [2,6].

However, while some progress has been made in incorporating innovative teaching methods in undergraduate courses, instructional laboratories have received relatively little attention [7]. Traditional laboratory experiments, although effectively used to strengthen theoretical concepts, are typically presented in a rigid format. Experimental objectives, testing methods, and equipment are often predefined in "cookbook" fashion. As a result, students are not afforded the opportunity to critically examine the task at hand.

PROPOSED MODEL

The proposed Structural Engineering Instrumentation and Measurements (SEIM) Laboratory model challenges students to answer the *What*, *When*, *How*, and *Why* of experimental design. The Laboratory introduces, integrates, and educates civil engineering students at the senior level about current practices of non-destructive structural testing and evaluation. The overarching goal of the proposed lab is to encourage students' critical and creative thinking while strengthening technical and analytical skills. The SEIM model builds on accepted methods of instructions [2, 8-10] by employing a progressive learning approach (i.e. successive laboratory modules increase in complexity). More significantly, the experiments are open ended, allowing student teams to ***design their own experiments***. In this manner, students are challenged to clearly define an engineering problem, effectively collaborate and communicate with group members, creatively outline several testing approaches, convincingly formulate arguments, and productively deal with diverse perspectives within a group. A schematic description of the SEIM model is shown in Figure 1.

This form of discovery-based learning is supported by a number of studies [11-13]. The NSSE reports that a shift from passive, instructor-dominated teaching to active, learner-centered activities promises to have desirable effects on learning [1].

In the 2002 report, "*Greater Expectations: A New Vision for Learning as a Nation Goes to College"* by the Association of American Colleges and Universities (AACU), the importance of promoting intentional learners and thinkers is highlighted [14]. "Intentional learners" are defined as students who can adapt to new environments, integrate knowledge from different sources, and contribute learning throughout their lives, while "intentional thinkers" are those who can see connections in seemingly disparate information and draw on a wide range of knowledge to make decisions. More recently, the AACU partnered with The Carnegie Foundation for the Advancement of Teaching to create the Integrative Learning Project: Opportunities to Connect. In a resulting report, the intellectual and emotional appeal of integrative learning is credited with fostering a student's capacity to connect ideas through discovery and creativity and intensifying a student's enthusiasm about learning [15].

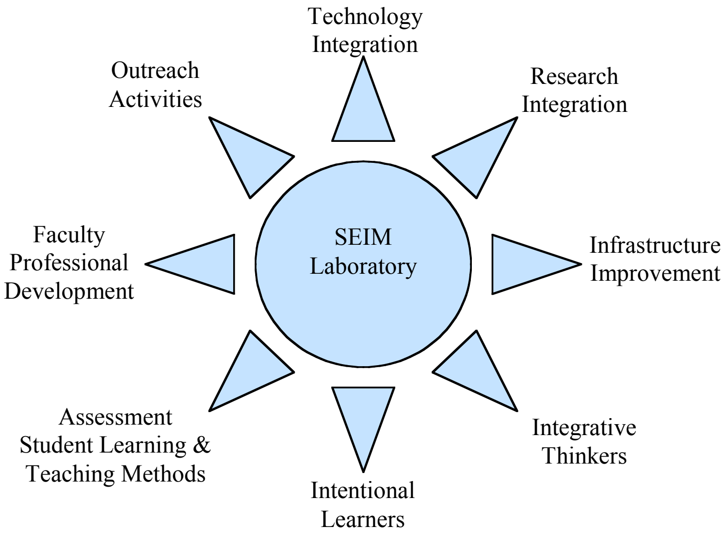

Figure 1 SEIM Laboratory Model

Promoting intentional, integrative learning is not necessarily new to the Civil and Environmental Engineering (CVE) department at the University of Rhode Island (URI). The Department currently offers a two-semester senior capstone design course (CVE 497, 498) in which students are divided into "consulting firms" each with a discipline-specific representative (i.e. project manager, structural, geotechnical, transportation, hydraulics, and environmental engineering). Each student group works together on a real-world project in response to a Rhode Island Department of Transportation (RIDOT) request for proposal (RFP) in a mock office setup. During the semester, students prepare written reports, make site visits, correspond with participating RIDOT engineers, and seek technical advice from faculty. At the conclusion of the project, students present a final report to a review panel and essentially "compete" for the job.

The hope of the Department is to extend this student-centered learning environment to the area of structural engineering. By allowing students to take control of their work, students will become more self-aware and deliberate in their efforts while demonstrating intellectual agility. It is anticipated that the two-credit senior-level SEIM Laboratory replace the current junior-level, one-credit Structural Engineering Laboratory (CVE 355). Partial funding for this initiative is provided by the URI Foundation.

LABORATORY MODULES

The Laboratory is organized into six multi-week modules of increasing complexity. Each module is developed in a standard format that includes specific learning objectives, topical background information including theory, and assessment tools. The lab modules are designed to provide learning opportunities in a range of structural instrumentation topics. Figure 2 provides an overview of the laboratory framework. The modules are structured to address three main concepts, namely introductory concepts, structural vibration, and structural damage.

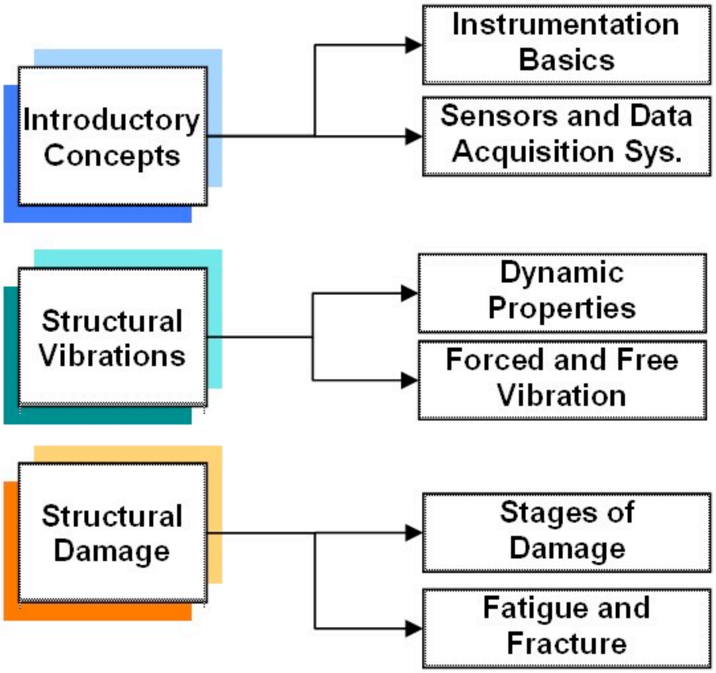

Figure 2 Laboratory Module Framework

A brief description of each module is provided below. At the conclusion of each module, student groups are required to submit "laboratory reports" by creating a team website. In this manner, students are encouraged to effectively and concisely communicate their experimental approach and interpretation of data. Student-generated websites also makes it easier for student and program assessment as well as for dissemination efforts.

MODULE (1) Instrumentation Basics

This module serves as a tutorial of basic concepts of instrumentation to civil engineering students. Measurement theory including electrical quantities, resistance, direct and alternating current, and power supply is discussed. Conversion of electrical measurement signals into physical units of the measured response is addressed.

MODULE (2) Sensors and Data Acquisition Systems

This module introduces the functioning and theory of various sensors and data acquisition systems to students. Sensors include strain gauges, accelerometers, linear variable differential transducers (LVDT), and laser Doppler vibrometer (LDV). Topics also include signal conditioning, oscilloscopes, instrumentation setup, calibration, and proper testing practice. Current professional practice of the use of sensors and instrumentation for non-destructive testing and evaluation of structures is also highlighted.

MODULE (3) Dynamic Properties

This module offers a review of basic properties and behaviors of structures such as strength, stiffness, redundancy, energy absorption during deformation, and natural frequencies. Students are encouraged to relate measured response to basic structural properties.

MODULE (4) Forced and Free Vibration

This module presents an overview of forced and free vibration, damping, natural frequencies, and resonance. Beams and trusses of varying configuration are subjected to static and dynamic loading. Experimental determination of natural frequency and damping ratio from free vibration are performed. Students also develop simplified analytical models of test specimens and correlate measured response to numerical predictions.

MODULE (5) Stages of Damage

This module introduces students to various types and stages of structural damage due to environmental conditions or excessive and repetitive loading. Experiments are performed using cantilevered aluminum beams with different damage scenarios (i.e. loss of section or stiffness). The effect of damage on the displacement signature and dynamic properties of the specimen is investigated. Current non-destructive tests (i.e. ultrasonic and chloride test systems) as well as vibration-based detection methods (i.e. changes in natural frequencies) are discussed.

MODULE (6) Fatigue and Fracture

This module introduces the concepts of fatigue and fracture. Students examine different specimens subjected to varying degrees of fatigue damage. The effect of surface cracks and defects and the influence of different factors on material fatigue are also discussed. Current methods including acoustic emission (AE) for detecting fatigue and fracture behavior of materials are highlighted.

PROGRAM OUTCOMES

The SEIM Laboratory program outcomes are outlined in Table 1. The outcomes are formulated to reflect specific program objectives that include components from three domains of knowledge, namely cognitive, psychomotor, and behavioral. Program objectives are adapted from a 2002 colloquy organized by the Sloan Foundation at the request of ABET to discuss the fundamental objectives of engineering instructional laboratories [16-18].

Table 1 SEIM Laboratory program outcomes

Knowledge Domain	Program Outcome	Description
Cognitive	**a) ability to identify, formulate, and solve engineering problems**	- develop a true understanding of the engineering problem - establish a sound experimental approach and testing procedure - identify proper equipment for successful execution of test objectives - design and conduct experiments - collect and interpret data - evaluate whether a theory adequately describes observed behavior - validate relationship between measured data and theoretical concepts
	b) knowledge of basic research techniques	- gather information from a variety of sources - conduct a literature review of accepted testing methods - become familiar with leading technical journals in the field
Psychomotor	**c) ability for creative and critical thinking**	- formulate and evaluate different testing methods in the group - forecast test outcomes and possible hurdles in the experiment - outline and compare alternative approaches - develop self-monitoring and reflective skills
Behavioral	**d) proficiency in written and oral communication skills**	- develop well-reasoned argument - effectively communicate one's argument in a group setting - develop a team website for concise and effective communication of experimental approach and interpretation of data - evaluate other groups' oral presentation according to established criteria
	e) ability to function on diverse teams	- develop an understanding of group dynamics - enhance communication and negotiation skills for dealing productively with conflict or diverse perspectives - work cooperatively and effectively with others - encourage active participation of others

PROGRAM ASSESSMENT

Assessment of student learning is an integral and important component that should be considered throughout the educational process [19]. The SEIM Laboratory assessment plan includes scientific ability rubrics, student surveys, and course evaluations. The rubrics developed and tested by the Rutgers Physics and Astronomy Education Research (PAER) group [20-22], are used to provide formative assessment of students and monitor improvement. The rubrics assess different abilities that scientists and engineers use in their work, such as designing and performing experiments, collecting and analyzing experimental data, devising and critically comparing alternate approaches (divergent thinking), and communicating scientific results. The rubrics contain many sub-abilities, each of which is scored on a scale of 0 to 3. A small portion of the rubrics is shown in the following table. A complete set of rubrics is available on the Rutgers PAER website [22].

Table 2 A portion of the scoring rubrics used for a problem-solving design experiment

Ability / Score	**0**	**1**	**2**	**3**
Is able to design a reliable experiment that solves the problem	The experiment does not solve the problem.	The experiment attempts to solve the problem but due to the nature of the design the data will not lead to a reliable solution.	The experiment attempts to solve the problem but due to the nature of the design there is a moderate chance the data will not lead to a reliable solution.	The experiment solves the problem and has a high likelihood of producing data that will lead to a reliable solution.
Is able to evaluate the results by means of an independent method	No attempt is made to evaluate the consistency of the result using an independent method.	A second independent method is used to evaluate the results. However there is little or no discussion about the differences in the results due to the two methods.	A second independent method is used to evaluate the results. Some discussion about the differences in the results is present, but there is little or no discussion of the possible reasons for the differences.	A second independent method is used to evaluate the results. The discrepancy between the results of the two methods and possible reasons are discussed. A percentage difference is calculated in quantitative problems.
Is able to suggest experiments from diverse contexts to accomplish the desired goals	No attempt is made to suggest experiments from different contexts.	Multiple experiments are suggested but they are essentially from the same context.	Experiments are suggested from multiple contexts and they are appropriate, but are described vaguely or incompletely.	Experiments are suggested from multiple contexts and they are described clearly.
Is able to evaluate specifically how experimental uncertainties may affect the data	No attempt is made to evaluate experimental uncertainties.	An attempt is made to evaluate experimental uncertainties, but most are missing, described vaguely or incorrect.	Most experimental uncertainties are evaluated correctly, though a few contain minor errors, inconsistencies, or omissions.	All experimental uncertainties are correctly evaluated.

CONCLUSIONS

Current professional practices of non-destructive structural testing and evaluation need to be infused into the civil engineering undergraduate curriculum. In particular, student comprehension of basic instrumentation, structural dynamics, and structural damage is important. The SEIM Laboratory offers students this opportunity through active experiences. The Laboratory takes a progressive learning approach in which successive lab modules increase in complexity. More significantly, the experiments are open ended, allowing student teams to design their own experiments. Consequently, students become more self-aware and deliberate in their efforts while expressing intellectual freedom and agility. For each of the six laboratory modules, students are provided specific learning objectives, topical background information including theory, and assessment tools. The modules are motivated primarily by observation and experiential learning rather than theory-driven. This approach is well-suited for undergraduate students' introduction to complex topics. It is anticipated that the senior-level, two-credit SEIM Laboratory replace the current junior-level, one-credit Structural Engineering Laboratory (CVE 355) in the Department of Civil and Environmental Engineering at the University of Rhode Island.

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