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Performance Assessment
for Civil Engineering Curriculum

Abstract

The accreditation of engineering education programs by the Accreditation Board for Engineering and Technology (ABET) requires the direct assessment of student's learning to ensure they meet the requirements of particular program outcomes. Past attempts of measuring student's learning in Civil Engineering have largely relied on a few isolated data points and unreliable satisfaction surveys. Hereafter the authors propose a systematic approach for directly assessing the student performance across an entire program which includes the current ABET requirement as well as the Body of Knowledge (BOK) of the American Society of Civil Engineering (ASCE). The approach is based on embedded signature assessments and concept inventories, which originate from the field of educational psychology. These direct assessment methods lead to quantitative assessments of student performance without dramatically increasing faculty work load and generating tedious data collection; they enhance what is typically accomplished in the evaluation and grading of student work. The greatest benefit of using embedded signatures and concept inventories is to provide a rapid, multi-factored, quantitative assessment, and to provide instructors and administrators with the immediate, comprehensive feedback they need to promptly address student needs. This relatively simple yet thorough assessment process enables administrators to devote time to curriculum improvements instead of collecting and compiling assessment data with limited application focus. The performance methodology, although tested in this particular case with Civil Engineering, is applicable to other fields of Engineering.

Introduction

In response to the requirements of the Accreditation Board for Engineering and Technology (ABET) for assessing the performance of students in Civil Engineering in relation to particular program outcomes, many educational institutions have developed assessment methods based on satisfaction surveys, senior-level capstone design courses, and Engineer-in-Training examinations. In the past, assessors have struggled to find realistic and acceptable ways to assess student achievements across entire programs so that they meet ABET requirements as well as other professional recommendations, e.g., the Body of Knowledge[3] (BOK) of the American Society of Civil Engineering (ASCE). Many institutions have painfully realized that the assessments of student learning performance can result in dramatically increasing faculty work load and generating time-consuming data collection with uncertain results.

Inspired by past work on student's assessment[7], the objective of the paper is to explore the application of concepts originating from the field of educational psychology to engineering education, and to propose efficient and effective ways to assess student learning performance.

Following the introduction, the first section of the paper reviews the background for assessing student's learning, especially the reasons why higher education had to become more accountable in delivering relevant engineering education; the second section reviews basic concepts in educational psychology relevant to performance assessment; and the last section summarizes some preliminary results on how to measure student's learning and achievements in relation to particular program objectives.

Background

The National Academy of Engineering (NAE) has alerted the Nation that engineering education must adapt to world changes in technology and society for the US to strengthen its workforce and face the challenges of globalization[12, 13]. NAE[13] quotes the National Science Board "The organizational structures for educating, maintaining skills, and employing science and engineering talent in the workforce are diverse and their interrelationships complex and dynamic. As a result, production and employment of scientists and engineers are not well understood as a system[14]." NAE states that "although progress is being made in engineering education, much remains to be done in developing research base underlying best practices in engineering education[18] and faculty practice generally[2]." NAE presents a suite of recommendations summarized in Table 1.

Table 1. Excerpts from NAE Recommendations[13].

- The B.S. degree should be considered as a pre-engineering or "engineer in training" degree.
- Engineering programs should be accredited at both the B.S. and M.S. levels so that the M.S. degree can be recognized as the engineering "professional" degree.
- Institutions should take advantage of the flexibility inherent in the EC2000 accreditation criteria of ABET, Incorporated in developing curricula, and students should be introduced to the "essence" of engineering early in their undergraduate careers.
- Engineering educators should introduce interdisciplinary learning in the undergraduate curriculum and explore the use of case studies of engineering successes and failures as a learning tool.
- The engineering education establishment should participate in efforts to public understanding of engineering and the technology literacy of the public and efforts to improve math, science, and engineering education at the K-12 level.

ABET, the primary accrediting body for engineering undergraduate programs, has for goal of ensuring the quality of undergraduate engineering science and technology programs through rigorous review and monitoring. As listed in Table 2, ABET approved a set of hard and professional skills that graduates must possess[16]. These skills extend beyond the minimalist standard of engineering practice to include professional standards that are of high quality, multidisciplinary, global and with collaborative focus.

The American Society of Civil Engineering (ASCE) is actively engaged in articulating an inspirational global vision for the future of civil engineering[4]. ASCE attempts to align stronger academic experience with anticipated future application-based workplace requirements. ASCE[3] supports the attainment of a "Body of Knowledge" for entry into the practice of civil engineering at the professional level. This would be accomplished through the adoption of appropriate engineering education and experience requirements as a prerequisite for licensure. Fulfillment of this Body of Knowledge will combine a baccalaureate degree; a master's degree, or approximately 30 coordinated graduate or upper level undergraduate credits or the equivalent agency/organization/professional society courses providing equal quality and rigor; and appropriate experience based upon broad technical and professional practice guidelines which provide sufficient flexibility for a wide range of roles in engineering practice.

Table 2. ABET outcome criteria for engineering baccalaureate graduates.

Hard skills	3a: An ability to apply knowledge of mathematics, science, and engineering
	3b: An ability to design and conduct experiments as well as to analyze and interpret data
	3c: An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, heath and safety, manufacturability, and sustainability.
	3e: An ability to identify, formulate, and solve engineering problems.
	3k: An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
Professional Skills	3d: An ability to function on multi-disciplinary teams
	3f: An understanding of professional and ethical responsibility
	3g: An ability to communicate effectively
	3h: The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context.
	3j: A knowledge of contemporary issues.

Review of education improvements in Civil Engineering

Civil engineering is a broad field of engineering dealing with the planning, design, construction, maintenance and management of physical infrastructure networks, e.g., power plants, bridges, roads, railways, structures, water supply, irrigation, the natural environment, sewer, flood control, transportation and traffic[19]. Educational programs and practices in civil engineering have been incrementally revised and adapted over the years. Typically a BS program in civil engineering is comprised of a sequence of courses in Mathematics, Physics, Chemistry, Biology, Humanities, Business, and a few other fields of Engineering. Table 3 shows an example of curriculum in civil engineering at the University of Southern California (USC), which is accredited by ABET. This program is representative of many other curricula in universities and colleges throughout the United States. The program consists of a series of 40 courses, which can be regrouped in 9 main subject categories. Students take all their mathematics, physics and chemistry courses as freshman and sophomore, become gradually exposed to civil engineering over four years, and specialize in civil engineering as junior and senior.

So far most educational institutions have responded to the challenging tasks of reforming engineering education with traditional approaches, which unfortunately have produced incremental and slow improvements. Reformers face often tremendous difficulties and even resistance in their attempts of modifying curricula that have been gradually perfected through years of incremental revisions. Many educational institutions are attempting to reform engineering education based on their own experiences in engineering. However they struggle with incremental and introverted changes because they do not use expertise beyond engineering, such as educational psychology.

Table 3. Example of ABET-accredited BS program in Civil Engineering.

	Course	Description	Prerequisites	Co-requisites
	Math 108 or Math Placem			
	CHEM 050/Chemistry Pla	Basic requirement for taking courses in chemistry		
	Junior or Senior Standing	Prerequisite for some courses		
Fall 1	CE 106	Design and Planning of Civil Engineering Systems		
Fall 1	ENGR 102	Engineering Freshman Academy		
Fall 1	Math 125	Calculus I	Math 108 or Math Placement Exam	
Fall 1	Writ 140	Writing and Critical Reasoning		
Fall 1	Category 6: Social Issues			
Spring 1	CE 107	Introduction to Civil Engineering Graphics		
Spring 1	CE 108	Introduction to Computer Methods in Civil Engineering		
Spring 1	Math 126	Calculus II	Math 125	
Spring 1	Phys 151L	Fundamentals of Physics I: Mechanics and Thermodynamic	Math 125 or Math 126 or Math 226	
Spring 1	Select One CHEM Course			
Fall 2	CE 205	Statics	Phys 151L	
Fall 2	Math 226	Calculus III	Math 126	
Fall 2	Phys 152L	Fundamentals of Physics II: Electricity and Magnetism	Phys 151L, Math 126	Math 226
Fall 2	Select One GE Course			
Fall 2	Select One GE Course			
Spring 2	CE 225	Mechanics of Deformable Bodies	CE 205	
Spring 2	CE 207L	Introduction to Design of Structural Systems	CE 107, CE 205	CE 225
Spring 2	Math 245	Mathematics of Physics and Engineering I	Math 226	
Spring 2	CE 325	Dynamics	CE 205	
Spring 2	Select One Course			
Fall 3	CE 309	Fluid Mechanics	Math 226	CE 325
Fall 3	CE 358	Theory of Structures I	CE 225	
Fall 3	CE 456	Design of Steel Structures	CE 207L, CE 225	CE 358
Fall 3	CE 334L	Mechanical Behavior of Materials	CE 225 or AME 204	
Fall 3	Select One GE Course			
Spring 3	CE 473	Engineering Law, Finance and Ethics		
Spring 3	CE 451	Water Resources Engineering	CE 309 or ENE 410	
Spring 3	CE 467L	Geotechnical Engineering	CE 225	
Spring 3	Select One EE Course			
Spring 3	Select One Kernel			
Fall 4	CE 408	Risk Analysis in Civil Engineering	CE 225, Math 226	
Fall 4	CE 453	Water Quality Control	CHEM 105aL or CHEM 115aL	CE 408 or CHE 405, CE 309 or ENE 41
Fall 4	CE 471	Principles of Transportation Engineering		
Fall 4	Select One Kernel			
Fall 4	Select One CE Elective			
Spring 4	Select One Capstone			
Spring 4	CE 402	Computer Methods in Engineering	CE 108, Math 245	
Spring 4	Writ 340	Advanced Writing	Writ 140	
Spring 4	Select One CE Elective			
Spring 4	Select One GE Course			

There is an urgent need for devising learning assessment tools that yield useful information for educators to improve effectively curriculum and course delivery mechanisms. As added benefits, these tools may assist educators and administrators in convincing external reviewers, e.g. ABET reviewers, that their particular programs meet specific outcomes and ABET requirements.

Educational Psychology as a Means of Transforming Engineering Curriculum

To accomplish this global vision of linking course work to field-based applications, the authors posit to apply widely researched educational psychology principles and practices to the engineering curriculum. These practices include:

- vignette-based instruction,
- embedded signature assignments,
- rubric judged laboratory experiences,
- value judged internships, and
- concept inventory assessments in all courses in the courses.

All five of these teaching practices combine assessment to instruction and are linked to student performance. Vignette-based instruction is described as a provision of instruction where students are provided with real world vignettes or workplace problems and must solve these vignette based issues or problems using principles perspectives and practices that they have learned in courses[1]. These are often group experiences and the resulting solutions are judged using carefully crafted numeric rubrics. Embedded signature assignments are critical assignments that are linked to accreditation standards and are summative measures of course content. They range from a criterion referenced examination to group or solo project. The assignments offer proof of within course learning[15]. Rubric judged laboratory experiences have most often been applied to K-12 sciences coursework however they are beginning to be applied to university course-based lab experiences. Rubrics for the laboratories are aligned to content standards (in the case of the proposal, to ABET standards and the ASCE Body of Knowledge). Numeric scores are assigned to the rubrics allowing the course instructors to quantify human behavior for statistical analyses and comparison across groups[6]. Value judged internships are often used in education, social work or other human services professions where internships are required as a precursor to graduation. The employer and the university intern supervisor use numeric measures to judge the performance of the intern. These measures link the course content to the interns' field practice. Concept inventories have been used in education for decades. These inventories are force choice surveys in which misnomers related to content are contrasted with concept truisms in an attempt to statistically judge increases in concept knowledge over time or as a pre and post test measure. These formative and summative assessment-based experiences have been tested in K-12 and human services higher education programs but are not widely used in engineering programs. The authors goal is to use these instructional practices and associate assessment in the undergraduate civil engineering coursework with an ultimate goal of scaling up these practices school-wide in the Viterbi School of Engineering and eventually in other science based curriculum at USC.

Preliminary research results

The long-term objective of this research is to reform engineering education by applying well established techniques in educational psychology to engineering and other scientific curricula. These techniques have been developed and tested in education settings predominantly in K-12 schools, but have not received significant attention in university settings to measure student learning and education program performance particularly in engineering and other science oriented schools and academic departments.

Examples of civil engineering curriculum can be analyzed using both educational psychology and ASCE and ABET professional requirements. The educational psychology analysis invokes techniques such as concept inventory and vignette-based instruction. The analysis also accounts for best practices and professional requirements defined in the Body Of Knowledge (BOK) of ASCE, and the ABET accreditation requirements.

One of the key elements of this research consists of designing and implementing a performance system that monitors the progress and success of curriculum changes. The performance assessment is constructed using embedded signatures. Figure 1 illustrates how to embed signatures and relate course grades, graduation, and performance assessments. As shown in Fig. 1, the vertical axis represents a progression toward graduation, whereas the inclined axis represents a progression toward other goals set by different requirements, e.g., ABET accreditation and graduation based on minimum grade point average. This representation implies that not all students may satisfy both graduation and ABET requirements. Course grades, which are relevant for graduation, may not be sufficient for other requirements. Past attempts of measuring the ABET performance of Civil Engineering students have relied on a single senior-level capstone design course and end-of-course surveys. The authors propose a more direct and systematic assessment of student performance across an entire program which accounts for BOK and ABET requirements. This assessment, which measures quantitative performance, does not increase faculty workload and data collection; it builds upon the current practices of evaluating and grading students through the USC Blackboard system. The embedded signatures are defined by instructors and link desired program outcomes and course tests, e.g., projects, quizzes and exams. This monitoring system is anticipated to become accepted by instructors because it produces immediate quantitative feedback for promptly addressing course and program weaknesses.

The performance monitoring system is anticipated to yield a large volume of almost real-time information. This rapid feedback system departs from the time-consuming corrective processes which are occasionally in place through educational systems. It is emphasized that the proposed approach relies on quantitative performance measurements, instead of subjective interpretations such as student satisfaction surveys.

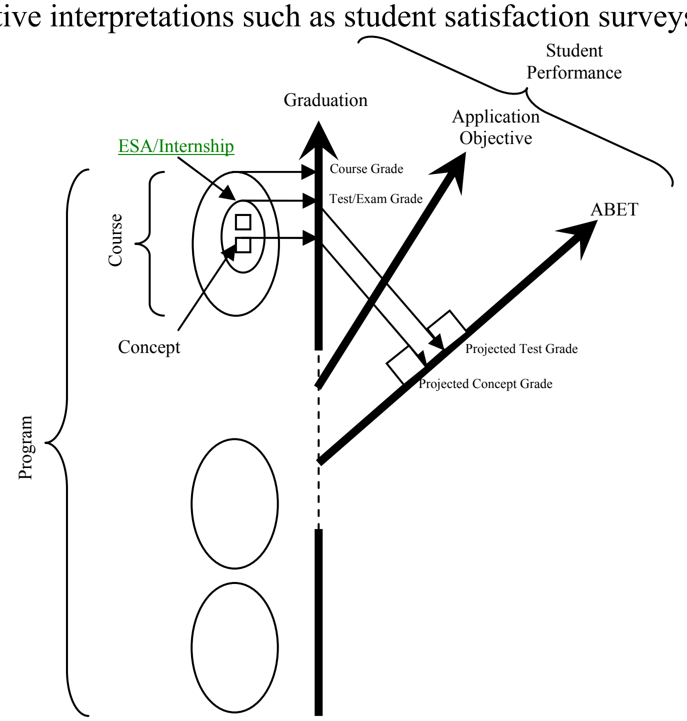

Figure 1. Integrated performance assessments for graduation and other requirements.

Conclusion

The accreditation of engineering education programs by ABET requires the direct assessment of student performance to ensure they meet the requirements of particular program outcomes. Past attempts of measuring student performances in Civil Engineering have largely relied on sparse and unreliable data collection. Hereafter the authors have proposed a systematic approach for directly assessing the student performance across an entire program which includes the current ABET requirement as well as the Body of Knowledge (BOK) of the American Society of Civil Engineering (ASCE). The approach is based on embedded signature assessments and concept inventories, which originate from the field of educational psychology. These direct assessment methods lead to quantitative assessments of student performance without dramatically increasing faculty work load and generating tedious data collection; they enhance what is typically accomplished in the evaluation and grading of student work. The performance methodology, although tested with Civil Engineering, is applicable to other fields of Engineering.

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