Evaluating Student Learning Across the Mechanical Engineering Curriculum

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Abstract

The Accreditation Board for Engineering and Technology (ABET) has a number educational objectives for engineering programs. In order to assess the success of an engineering program in meeting these objectives, a number of outcomes are traditionally used including course performance, faculty assessment, standardized testing, GPA, and surveys of graduates and employers. In this project, the Mechanical Engineering department at the University of Kansas examined using the senior capstone design poster presentations as a means to assess student learning across the curriculum. A rubric was created and deployed using industrial advisory board members to assess student performance. From this assessment, student learning was assessed and reported to the faculty for evaluation and discussion. This rubric and assessment of the senior capstone design presentations were found to be particularly useful in examining communication skills, design methodology skills, and the ability to design and conduct experimental evaluation and testing. The rubric was less informative on engineering analysis skills as design projects varied in scope and coverage of these areas.

Introduction

The Accreditation Board for Engineering and Technology (ABET) asks that all engineering programs work to achieve a series of educational objectives including:

a. an ability to apply knowledge of mathematics, science, and engineering
b. an ability to design and conduct experiments, as well as to analyze and interpret data
c. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d. an ability to function on multidisciplinary teams
e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility
g. an ability to communicate effectively
h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.[1]

In Mechanical Engineering at the University of Kansas, a number of outcome measures have been used to evaluate our students' progress towards these objectives including within-class evaluation of student performance, faculty assessment of pre-class preparation, standardized testing results (FE exam, ACT scores), senior exit interviews, employer surveys, and student GPA records[2]. As part of a university initiative to develop methods to evaluate student learning across-the-curriculum, the faculty of the mechanical engineering department chose to examine the use of the senior capstone design projects as an outcome measure of student performance. The senior capstone design projects offer an opportunity to develop more quantifiable measures. These projects are accomplished by teams of students ranging from 3-30 students and cover a wide array of work, from designing medical device testing equipment to designing and building a Society of Automotive Engineering (SAE) formula competition car. They share in common the design process and the need to apply knowledge from a wide range of classes. Therefore, the goals of this project were to develop a measure that could be used across different types of design projects and would be useful in examining our educational objectives. Our efforts targeted the presentations of the students when highlighting their efforts either through a poster presentation or design review meeting. For this initial effort, we focused on the annual capstone design poster presentations made in April during the visit of the Industrial Advisory Board.

Methods

To evaluate the senior design project presentations, a rubric was created. It was designed to evaluate students' performance along a number of dimensions viewed as important by the faculty and our industrial advisory board. These dimensions were:

- Identifying functional objectives
- Engineering analysis and methodology
- Evaluation and testing of design objectives
- Inventiveness and creativity
- Team chemistry, interest and passion for the work
- Written and visual presentation
- Oral presentation and questions

Within each dimension, categories were developed that described indicators of student performance from low to high. The rubric was first created in 2008 and was subsequently rewritten in 2009 in more concise language (Table 1). The rubric was created to fit on one page with areas on the back for comments on both the students' performance and on the usability of the rubric.

This rubric was first implemented in Spring 2008 at the student design final poster presentations. At the poster presentation, all student groups create a poster describing their projects and the engineering work involved. The students are asked to present at a poster session where fellow students, faculty, alumni on the advisory board, and others can visit their poster and ask questions of the students. At the student design poster presentations, we asked both external and internal reviewers to evaluate the design projects using the rubric. The outside reviewers include alumni advisory board members and industrial sponsors of the design projects. Internal reviewers were instructors and faculty in the department.

Identifying Functional Objectives				
Students have addressed all objectives and identified primary (key) and secondary (desired) goals. Key goals are matched in design plan.	Objectives clearly address design goals and client demands, but are *incomplete or missing some elements*. Objectives identify key goals and match design plan.	Objectives are *inadequately described or do not match with design plan*.	*Functional objectives do not appear to have been considered.*	Not Available
Engineering Analysis and Methodology				
The key design elements were all correctly and appropriately analyzed. Students demonstrated knowledge of key engineering concepts applied to a real life situation.	*Some analyses appear to be missing.* However, the analyses that are described appear to be correct and demonstrate sound knowledge of engineering concepts.	Analyses that should have been performed were *missing or performed incorrectly*. Students appear *not to understand some key engineering concepts*.	*Students did not demonstrate knowledge or understanding of key engineering concepts.*	Not Available
Evaluation and Testing				
Students have developed a full and appropriate evaluation of the design to assess appropriate design objectives. Experimental methodology is clearly described and correctly implemented.	Students have developed an evaluation and testing plan that assesses appropriate design objectives *but could be more clearly described or should be more thorough.*	Evaluation and testing plan is clearly described but *does not appropriately assess design objectives.*	Evaluation and testing plan *does not appear to have been considered but should have been.*	Not Available
Inventiveness and Creativity				
Innovative or creative thinking is *evident* (even if the eventual design is more traditional).	Developed design showed *some* innovation and creativity. *Some* clever or creative components were included in the design.	Students designed a reasonable and functional product but *do not appear to have gone far beyond existing approaches*.	Students showed *little creativity and innovation in their design.*	Not Available

Table 1. Rubric Questions for Poster Evaluation The rubric was presented on 1-page, but is presented here in two pages due to margin limitations.

Team Chemistry, Interest and Passion for the Work				
The students are excited about their work and animated in their presentation of the work.	There is *mixed enthusiasm* within the group or by the presenter.	Students put on a good face, but go through the motions *without real enthusiasm*.	*Students appear to be uncommitted or disinterested.*	Not Available
Written and Visual Presentation				
The poster is clearly organized, easy to read, and visually interesting. There are few obvious mistakes.	The poster is *fairly* clear, easy to read and visually interesting. *There are some editing mistakes or difficult to read graphics.*	This poster is not hard to read, *but are not well formatted or have significant editing mistakes*.	*The poster is poorly organized and difficult to read.*	Not Available.
Oral Presentation and Questions				
Students speak clearly, make eye contact, and show a solid understanding of material. Students answer difficult questions with ease.	Students speak clearly, make eye contact, and show a solid understanding of material. *Students have some difficulty answering questions.*	Students speak clearly, make eye contact, and show general understanding of material. *Students have significant difficulty answering questions.*	*Students do not speak clearly or show limited understanding.*	Not Available.

Table 1 continued. Rubric Questions for Poster Evaluation. The rubric was presented on 1-page, but is presented here in two pages due to margin limitations.

After the first implementation, the rubric form was refined based on comments from the users. These comments included that the rubric was 'too wordy'. To clarify the form, differences between proficiency levels were italicized. In addition, a second version of the form for oral (rather than poster) presentations was created so the form could be used in other design presentations throughout the year. This was again used for the student design poster presentations in Spring 2009 and Spring 2010. The form and the composite scores from the reviewers were presented to the Mechanical Engineering faculty at their regular faculty meetings and the annual faculty retreat.

Results

In the first implementation of the rubric, the scores were quantified on a 1-4 scale (4 as mastery) to obtain the following table:

	Objectives	Analysis	Evaluation	Creativity	Interest	Written	Oral
Advisory Board	3.48	3.27	3.00	3.00	3.54	3.45	3.69
Faculty	3.62	3.50	2.85	3.42	3.77	3.77	3.81

Table 2. Composite Scores from the 2008 Annual Student Design Poster Presentations for All Design Groups.

From this, a number of observations are drawn:
1. Faculty, in general, rated the creativity of the student groups more highly than the advisory board. In faculty discussions, it was noted that faculty are more familiar with the ability of the students and limitations of the project scope and duration. These limitations include that the choice of project is often proscribed by sponsors and the possible solutions can be limited by sponsorship funding and time available. Some projects do lend themselves to greater creativity.

2. Both faculty and advisory board members rated evaluation and testing lower than other scores. In faculty discussions, it was noted that evaluation and testing are often performed in the final stages of a design project, so presentations in April may not reflect the final levels of evaluation and testing performed. However, the faculty also discussed how exposure to evaluation and testing could be improved. Currently there are several courses that include experimental work that would develop these skills. In many of these courses, experimental work is 'pre-designed' to allow students to do an experiment quickly. It may be possible, in the future, to incorporate student experimental design into such courses to further expose students to such work.

3. Many of the courses that are prerequisites for the capstone courses are in the area of engineering analysis and methodology. All but one student group were given scores of 3 or 4 by both the faculty and alumni. However, given the numbers of areas and courses this score covers, it would be desirable to expand the assessment of this area (do they know engineering analysis in fluid dynamics, for example). To do this, other student products may need to be assessed since not all design products require analysis of all engineering areas.

In Spring 2010, the students were again evaluated using the improved rubric (one of the 12 groups did not participate in the poster session this year). Assessments in this year were performed by the industrial advisory board members. The scores were as follows:

	Objectives	Analysis	Evaluation	Creativity	Interest	Written	Oral
Average Advisory Board	**3.46**	**3.32**	**3.20**	**3.01**	**3.52**	**3.62**	**3.65**

Table 3. Composite Scores from the 2010 Annual Student Design Poster Presentations for 11 of 12 design groups (one group was unable to participate).

In general, performance remained consistent with that of 2008. The advisory board members rated evaluation higher in 2010, perhaps due to encouragement by design faculty to include more evaluation components in their presentation or by changes in the measurement and instrumentation curriculum.

A challenge for the department during this period has been a large growth in the size of the undergraduate program, which has presented considerable strain on the laboratory classes including measurement and instrumentation classes. These results demonstrate that while the increased class size has been difficult, instructors in these courses have been able to be effective in maintaining and even improving student learning in these areas.

Discussion

The senior design courses in Mechanical Engineering are required for all seniors and use materials learned in many courses across the curriculum. As such, they are a good place to assess student learning comprehensively, allowing a large scale picture of overall preparedness and variability of that preparedness across the student body. A single, 1-page rubric that is simply written, can, in this setting, allow for easy and quantifiable assessment. Using faculty and outside observers (advisory board and industrial sponsors) is useful to obtain multiple perspectives.

From the work done here, it was observed that there are some strengths and limitations to using senior capstone design presentations as a measure of educational outcomes. The senior capstone design presentations offer an opportunity to capture student work across the entire senior class within the major. However, since the work is done in groups, it is harder to observe variations in individual performance or to relate that performance to other measures of an individual such as classroom performance in other classes. The presentations offer demonstrations of a wide variety of engineering, communication, economic, and broader impact skills in one place, but the level and completeness of this demonstration can be variable across projects. For example, one project may have more thermodynamics elements to the work while another may be more focused on solid mechanics and machine design. As such, it can be difficult to evaluate consistently, skills that are unevenly presented across projects. All project presentations, however, require demonstration of communication skills (both oral and written) and as such are suitable for assessment of these skills.

Future goals of this work include incorporating this outcome measure into department outcomes assessment processes (Figure 1), using this measure in other design courses including a freshman course that introduces design (ME 228) and a junior course that focuses on learning design principles (ME 501) to develop a longitudinal measure, and improving the rubric. In addition, variations of the rubric have been created to use in other senior capstone design presentations including interim oral reports and final oral design reports.

In conclusion, the senior capstone design projects offer a snapshot of the skills students have learned during their educational careers. Using the design poster presentations and a carefully designed rubric, a department can assess a number of educational objectives in one sitting. By including outside reviewers from industry, a department can obtain external validation of the quality of the education program and identify areas of improvement needed to prepare students for the workplace.

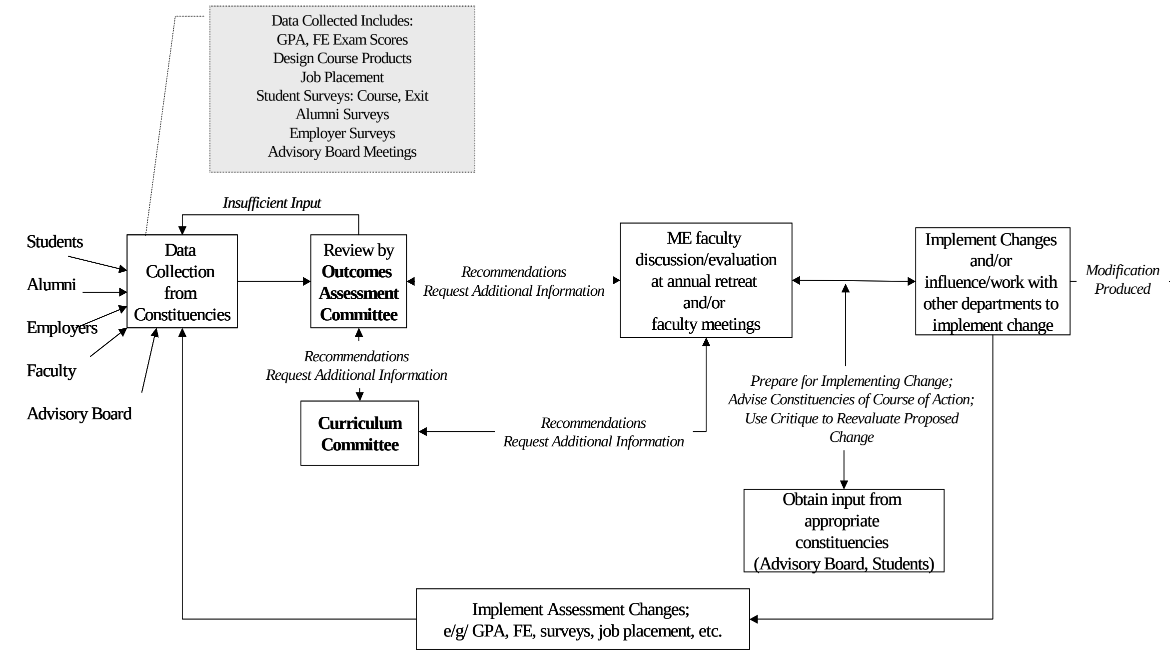

Figure 1. Feedback System of Learning Assessment and Improvement

References

[1] Engineering Accreditation Commission, ABET, 2009, "Criteria for accrediting engineering programs: effective for evaulations during the 2010-2011 accreditation cycle," ABET, Baltimore, MD.

[2] Mechanical Engineering, 2006, "KU-ME ABET Self Study," University of Kansas, Lawrence, KS.

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