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Objective and Quantitative Outcomes Assessment Using the Fundamentals of Engineering (FE) Examination*

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Over more than a decade, the authors have developed considerable experience in using the Fundamentals of Engineering (FE) Examination for objective and quantitative outcomes assessment. Results from the FE Examination are now sent directly from the National Council of Examiners for Engineering and Surveying (NCEES) to the institution and a variety of methods have been developed to analyze this data on a subject-by-subject basis. Three specific approaches to data analysis are presented: the percentage-correct method, the ratio method, and the scaled-score method. Each has its own pros and cons with regard to its use. Institutions can set student performance standards for individual topic areas, select one or more of the methods to graphically analyze the data, and then make decisions regarding instructional effectiveness in each topic area.

Keywords: assessment; outcomes; Fundamentals of Engineering exam

INTRODUCTION

INSTITUTIONS OF HIGHER EDUCATION are increasingly being encouraged to evaluate their academic programs with reference to a national norm or standard. This pressure may come from state legislators who want to assign cost–benefit labels and who want to measure the effectiveness of higher education, or it may result from accreditation requirements, which are becoming progressively driven by accountability and benchmarking. Whatever the reason, institutions must find practical, objective ways to assess their programs.

ASSESSMENT PROCESS

In engineering education, assessment has become a major topic as a result of the Accreditation Board for Engineering and Technology's (ABET) Engineering Criteria 2000 (EC 2000) [1, 2]. However, instructional effectiveness is difficult to measure and is often assessed by indirect, subjective methods. While various assessment tools have been used to evaluate instructional effectiveness, results have rarely been published or applied in a consistent manner. In addition, collected data may be misused or misinterpreted, leading to erroneous conclusions.

One effective tool for assessing certain aspects of engineering education is the NCEES Fundamentals of Engineering (FE) examination, sometimes called the EIT exam. This exam, developed to define minimum technical competence, is the first step in the professional licensing of engineers. It is a pass–fail exam that is taken by approximately 45 000 people a year, most of whom are recent college graduates or seniors within one year of graduating. Although exam results provide specific data on performance in a given subject, these data are not used directly for licensing. They can, however, serve as a valuable resource in making valid comparisons and conclusions when properly used in the assessment process.

Effective assessment of academic programs requires a set of tools and processes to evaluate various aspects of education. If the tools are to

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have any value as benchmarks or have credibility on an objective basis, the tools should make it possible to compare achievement of learning outcomes to an established goal. Assessment tools with this comparative value are particularly difficult to obtain. Methods such as portfolios or surveys lack quantitative performance standards.

Several studies have investigated methods of extracting subject specific data from FE Exam results and using the data as a part of a robust outcomes assessment process [3–6]. It is important to note that studies have also addressed the question of how to assure that the FE Exam results are reliable and valid measures of ABET required outcomes [7].

FUNDAMENTALS OF ENGINEERING (FE) EXAMINATION

As the only national examination that addresses specific engineering topics, the FE exam is an extremely attractive tool for outcomes assessment. In fact, since 1996, the FE exam has been formatted for the express purpose of facilitating the assessment process. For example, the discipline-specific exams for chemical, civil, electrical, environmental, industrial, and mechanical engineering were developed to include topics from upper-level courses—topics that were not appropriate when students from all engineering disciplines took the same exam. The exam content was revised to better measure students' knowledge of subjects taught in current junior- and senior-level engineering courses. The topics included in the discipline-specific exam were determined via surveys that were sent to every ABET-accredited engineering program in the United States. The most recent survey was conducted in 2004 and a new set of exam specifications went into effect for the October 2005 exam.

Through careful analysis, FE exam results may be used to assess particular aspects of the following ABET Criterion 3 outcomes: (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; (e) an ability to identify, formulate, and solve engineering problems; (f) an understanding of professional and ethical responsibility, and (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Although the FE exam does provide some means of assessment, employing the exam as an assessment tool that will provide effective information for program improvement requires good knowledge of the exam content and a well designed process for analysis of the exam results. For licensure purposes, the total score is evaluated rather than the score in any specific subset of questions. Passing the exam does not denote competence in all subjects but instead shows an average minimum competency in several subject areas.

A common error in using the FE exam results as an assessment tool is focusing on the percentage of candidates who pass the exam. This criterion is too broad to be effective in improving program outcomes; more specific measures are needed. Too often, the passing rates of individual programs are compared with those of other institutions, and these rates become more important than the subject matter evaluations. For continuous improvement, the focus must be on what the FE exam results can tell us about how well students have mastered the desired learning outcomes in specific areas, such as structural analysis or applications of calculus.

USING THE FE EXAM AS AN ASSESSMENT TOOL

In light of these limitations, how does one properly use the FE exam as an assessment tool? First, the department or program faculty should determine what subjects to teach and to what depth and breadth to teach them. This is a major part of the outcome goals set by each program as required by ABET EC2000. After establishing what topics to teach, faculty should set specific goals for student performance and then use the relevant portions of the FE exam to assess the students' knowledge in specific areas such as water resources, electric circuits, or machine design. The faculty should then compare their goals to the knowledge demonstrated by graduates of the program. For this assessment process to be valid, the population taking the exam must be representative of the entire population of graduates from the program. This can be accomplished either by having all seniors take the exam or by choosing a sample appropriately.

A related issue is ensuring that people who take the exam make an honest effort to complete all problems to the best of their ability. Analysis of FE examinees over a number of test administrations has revealed that few students fail to take the exam seriously. However, motivating the students to review materials before the exam, to prepare adequately for the exam, and ultimately to do their best work is a legitimate concern. Faculty who have doubts about whether students are putting in their best efforts should take steps to motivate them. Various methods are available to do this, such as informing them of the importance of the results to their future or actually requiring a passing score for graduation. Some programs that require all students to take the exam but do not require a passing score for graduation offer an incentive to do well by including pass–fail status on students' transcripts. Clearly, if the results are to be useful for outcomes assessment, the students must be performing in a way that accurately portrays their understanding.

FE EXAM TOPIC COVERAGE

To effectively use the FE exam as an assessment tool, faculty should know the specifications for the morning (AM) and afternoon (PM) exams as well as the level of understanding that the items are meant to measure. Specifications for the exams are available on-line at http://www.ncees.org/exams/fundamentals/fe_exam_specs.pdf [8]. Assessments will be more meaningful if students take the discipline-specific PM exam, which addresses more advanced engineering topics, rather than the general engineering PM exam. However, even the general exam will provide information on basic topics that are relevant to most programs.

FE EXAMINATION RESULTS

The NCEES publishes performance data on all FE exams administered. To make an effective assessment, faculty should request the proper performance data from NCEES so that comparisons are based on content congruent with their program. The NCEES Subject Matter Report summarizes data on EAC/ABET program examinees who took the exam while still enrolled in school. This is the statistical group that should be used as a measure of instructional outcome. This report is available directly from NCEES, but only if the examinees completed the portion of the answer sheet requesting institution and program information. An edited version of a Subject Matter Report for civil engineering is shown in Fig. 1.

APPLICATION OF FE EXAM RESULTS

Prior to the exam, faculty should determine the expected performance in each topic area, depending on the emphasis of that topic in their program. For example, if a program places little emphasis on surveying or transportation facilities, students should be expected to perform accordingly. Conversely, if the program has a strong emphasis on structural analysis, one would expect a much higher performance in this area compared with the national average. For more conclusive results, faculty should also consider performance over several administrations of the FE exam rather than from just one test administration. The form of this expected performance will depend on the analysis method chosen, a variety of which have been developed to examine the data from the Subject Matter Report with regard to program assessment. The three methods described in this paper are as follows:

1. Percentage-correct method
2. Ratio method
3. Scaled-score method

Percentage-correct method

This method utilizes the 'raw' data (% correct) directly from the Subject Matter Report. For example, assume that University X requires all graduating seniors in civil engineering to take (but not necessarily pass) the FE exam with the civil engineering PM portion and that the faculty expect students' collective performance to be as follows:

- Correctly answer at least 60% of the AM questions directly related to their major (engineering economics, ethics, fluids, math, probability and statistics, strength of materials, and engineering mechanics) and correctly answer at least 40% in the other topics.
- Correctly answer at least 60% of the PM questions that are emphasized in University X's program (hydraulics and hydrologic systems, structural analysis, structural design, soil mechanics and foundations, and surveying) and at least 40% in the other general civil engineering topics (construction management, environmental engineering, transportation, and materials).

Assume that the results for these students are represented by the Subject Matter Report shown in Fig. 1. A bar graph of the students' performance can easily be generated (see Fig. 2).

The assessment based on this one administration only (recognizing that a conclusive assessment will require evaluation of several exam administrations) yields the following:

- For the AM subjects, the civil engineering students met the expectation of correctly answering at least 60% of the questions in mathematics, probability and statistics, ethics, engineering economics, engineering mechanics and strength of materials. They exceeded the 40% expectation in chemistry, computers, material properties, and thermodynamics. In the remaining topics (fluid mechanics and electricity & magnetism), the students failed to meet the goals. In the assessment process, the faculty must determine if the expectations were too high or if the topic areas need attention. In fluid mechanics, perhaps the expectations were too high since the students correctly answered a higher percentage of the questions on this topic than students did nationally. In the other topic (electricity & magnetism), the students are performing just below the expectation. In any event, these topics need to be tracked over additional administrations of the FE exam and factors such as instructional methods, texts, and teaching mechanisms need to be evaluated.
- In the PM subjects, the students met all expectations except structural design. Since that topic is emphasized in University X's program, the university will need to track the topic over additional administrations of the FE, or the faculty may need to reevaluate their expectations. If the expectation is retained and performance remains

below this level, program changes are in order, which in ABET terminology is 'closing the loop'. This might involve adding coursework to the curriculum, modifying content of existing courses, or other changes.

It should be noted that expectations of faculty typically exceed actual performance of their students on the FE examination.

Ratio method

In many cases, the percentage-correct method produces unrealistic and perhaps unobtainable expectations for the students' performance (as mentioned previously concerning the topic of fluid mechanics). Moreover, the results of this method will be affected by the difficulty of a particular version of the FE examination. As an alternative to the percentage-correct method, faculty should consider using the ratio method to aid in developing reasonable expectations. For this method, the ratio of the performance at University X to the national performance is calculated for each topic area. The faculty then develops appropriate expectations from this scale, determining how much above or below the national average is acceptable for their students.

While a graph similar to Fig. 2 can be developed for the October 2005 exam, it is, as described in the previous section, more informative to graph the performance on individual topics over time. Figs 3 and 4 show such graphs for student performance in two areas emphasized by University X.

National Council of Examiners for Engineering and Surveying
Fundamentals of Engineering Examination
ABET - Accredited Programs

200510
1/4/2006

Currently Enrolled **Engineering**
Subject Matter Report by Major and PM Examination (formerly Report 5)

Board:	**State**	Institution:	Your University
Board Code:	XX	School Code:	XXXX
Major:	**Civil**	PM Exam:	**FE-Civil**

	Institution	State	National		Comparator Groupings		
Examinees Taking	11	11	2,211		814	920	187
Examinees Passing	11	11	1,469		611	699	131
Examinees Passing %	100	100	66		75	76	70

AM Subject	# Exam Questions	Institution AVG % Correct	National AVG % Correct	National Standard Deviation *	Carnegie 1 AVG % Correct **	Carnegie 2 AVG % Correct **	Carnegie 3 AVG % Correct **
Mathematics	19	75	59	3.3	61	57	53
Engineering Probability and Statistics	8	72	58	1.4	60	57	55
Chemistry	11	72	61	1.8	63	61	57
Computers	8	64	63	1.5	66	60	58
Ethics and Business Practices	8	91	79	1.2	80	78	76
Engineering Economics	10	77	69	1.8	70	68	65
Engineering Mechanics (Statics and Dynamics)	13	71	55	2.6	58	52	51
Strength of Materials	8	75	61	1.8	64	58	55
Material Properties	8	60	49	1.6	51	49	45
Fluid Mechanics	8	57	50	1.6	52	49	45
Electricity and Magnetism	11	36	41	1.9	42	40	39
Thermodynamics	8	59	47	1.6	48	47	42
PM Subject							
Surveying	7	75	59	1.4	60	59	57
Hydraulics and Hydrologic Systems	7	83	69	1.4	71	67	64
Soil Mechanics and Foundations	9	65	54	1.8	55	52	51
Environmental Engineering	7	71	58	1.4	59	57	54
Transportation	7	62	62	1.3	64	61	59
Structural Analysis	6	61	46	1.4	48	42	41
Structural Design	6	56	41	1.2	41	40	39
Construction Management	6	73	68	1.1	70	66	65
Materials	5	56	49	1.0	51	47	47

* The standard deviation above is based on number of questions correct not percentage of questions correct.

** Carnegie 1 - Research Extensive, Carnegie 2 - Research Intensive, Carnegie 3 - Masters I and II combined

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Fig. 1. Subject matter report.

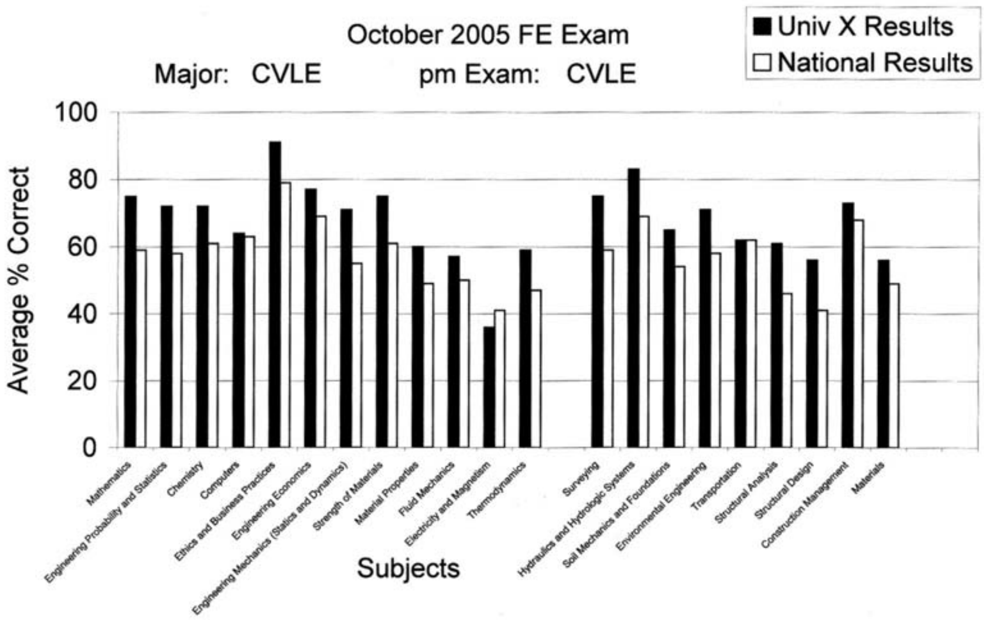

Fig. 2. Percentage correct for a specific exam date.

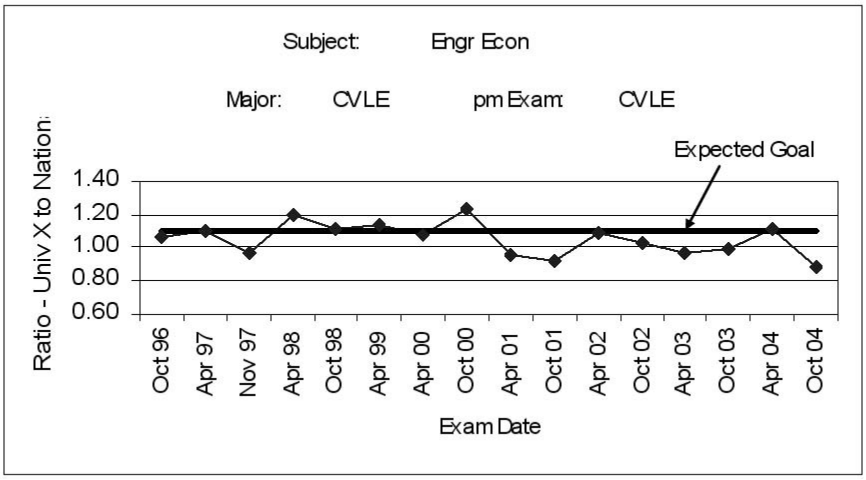

Fig. 3. Longitudinal study of University X's performance in engineering economics.

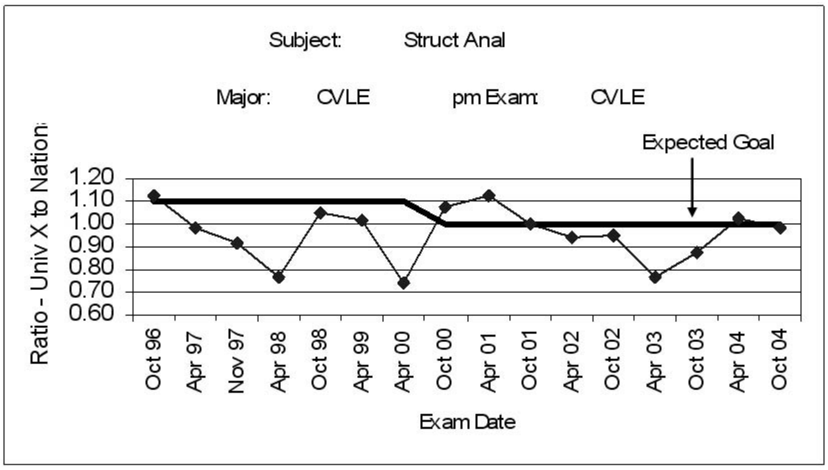

Fig. 4. Longitudinal study of University X's performance in structural analysis.

Regarding these two examples, one could draw the following conclusions:

- University X assumes that its civil engineering students should score 10% higher in these two core subjects than the national average for civil engineering students. (Recall that the Subject Matter Report only reports national performance data for students in the same major.) The authors would argue, however, that this is a somewhat lofty and perhaps unobtainable goal for University X.
- Despite the loftiness of the university's goal for engineering economics (Fig. 3), the students have consistently been near it. Significant fluctuation occurred between April 2000 and October 2001, which, for example, may have been the result of a change from a long-time instructor to a new one. This drop in performance should have spurred a study of this subject, especially since the students' performance has effectively been slightly below the goal since October 2001. If a more reasonable goal might be 1.00, or at least no larger than 1.05, the University is meeting the new expectation.
- According to Fig. 3, the results of the October 2004 exam show a dramatic drop below the expected goal. The authors suggest that an institution should not react to a single drop below the goal, but should continue to monitor the situation.
- For structural analysis (Fig. 4), note that University X determined that their initial goal of 1.1 was too high and that the goal was changed to 1.00 before the October 2000 exam. This type of 'close the loop' feedback is certainly acceptable. However, even with a lower goal of around 1.00, performances continued to fall short of expectations in April 2002, October 2002, and April 2003. Apparently, some decision was made regarding course work in this area, causing the performance to rise back up to expected levels.
- In an effort to smooth out the performance—especially in subjects that might be covered very late in the curriculum—one can also average the April and October results and plot the yearly average ratios.

Scaled-score method

The concept of the scaled-score method became possible following the April 2001 examination. The Subject Matter Report for that administration included, for the first time, standard deviation data. The standard deviation is based on the number of problems correct, not on the percentage correct and is generated from the test scores of a specific group of examinees. In Fig. 1, for example, the relevant group would be the civil engineering majors who selected the Civil PM exam at the October 2005 administration. Thus, pertaining to this group, the national performance for engineering economics could be stated as having a mean, $\bar{x} = 0.69 * 10 = 6.9$ problems correct and a standard deviation, $\sigma = 1.8$ problems. Further examination of Fig. 1 reveals that in all subjects, $\pm 3\sigma$ effectively covers the entire range from 0% correct to 100% correct.

The scaled-score was developed to allow universities to do the following:

- Present the data in a form that represents the number of standard deviations above or below the national average for each topic (as compared with the percentage above or below the national average given by the ratio method).
- Estimate the range of uncertainty in the university's performance to account for small numbers of examinees.

The scaled-score is defined as:

Scaled Score

$$= \frac{\#\text{ correct at Univ X} - \#\text{ correct nationally}}{\text{national standard deviation}}$$

$$= \frac{\#\text{ of questions (\% correct at Univ X} - \text{\% correct nationally)}}{\text{national standard deviation}}$$

The estimate of uncertainty (which allows an

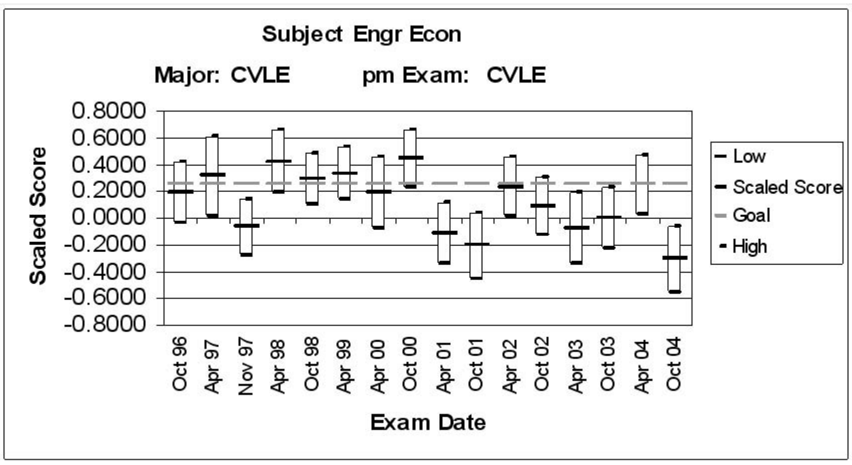

Fig. 5. Scaled-score results for University X's performance in engineering economics.

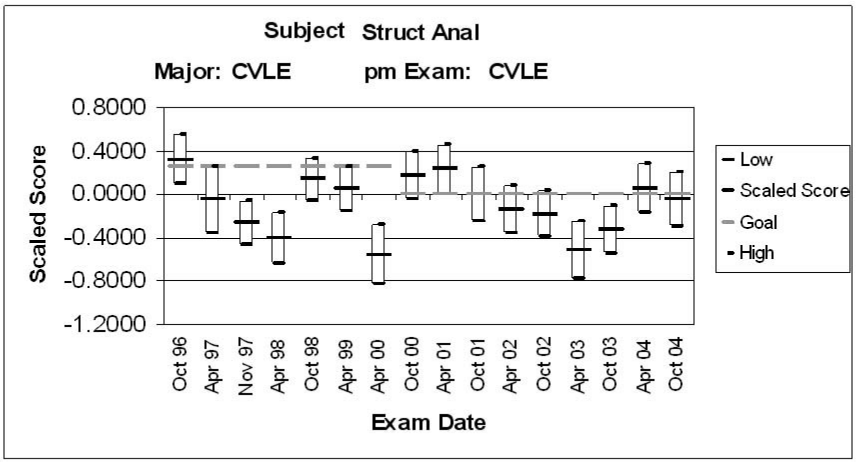

Fig. 6. Scaled-score results for University X's performance in engineering economics.

institution to account for low numbers of examinees) is given as:

$$\text{Range of Uncertainty} = \frac{\pm 1}{\sqrt{\#\text{ of examinees at Univ X}}}$$

The derivation of this uncertainty range can be found in the NCEES White Paper [9].

For the same topics previously discussed, the scaled-score graphs and some observations are as follows:

- For engineering econ, a ratio goal of 1.1 translated to a Scaled Score goal of 0.25.
- Even with the range of uncertainty, the Oct 2004 results (shown in Fig. 6) still indicate that engineering economics should be monitored over the next few exams.
- Even with the range of uncertainty, the April and October 2003 results for structural analysis (shown in Fig. 7) warranted action. From the subsequent results, evidently University X did take some kind of remedial action.

OTHER ISSUES

In making an assessment using the FE exam results, faculty must also consider that some students may not have taken the coursework before taking the FE exam. For example, some students take structural design in the spring semester of their senior year; therefore, those who take the FE in October of their senior year will not be prepared for that subject area. To provide some insight into these factors and allow faculty to consider such factors in making their assessment, some institutions have developed an FE exam exit questionnaire. An example is shown in the NCEES White Paper [9].

Effective assessment should result in continuous program improvement. Faculty should evaluate the results of student performance in individual subject areas. Doing so will identify those areas in which students are performing below the goals established by the faculty and perhaps significantly below national or state averages. Evaluations should instigate not only the necessary changes in textbooks, teaching mechanisms and laboratory procedures but also the possible reallocation of faculty to improve student performance. In one documented case in which FE exam results were used, student performance was significantly below the national average in hydraulics and hydrologic systems. The department head was surprised because the student evaluations for the course had been very good over several years. However, upon investigation, he found that the laboratory procedures used to reinforce the theory were shallow and that the performance demand on the students was low. The laboratory procedures and depth of instruction were improved over several semesters without lessening instruction on the theory. The most recent examinations indicate a significant improvement in student performance in this area. A point that cannot be overemphasized is that for assessment purposes, the results of multiple exams should be considered and the exam content compared with the course content.

CONCLUSIONS

After more than a decade of experience using the FE exam for outcomes assessment, the authors find it to be a useful part of a balanced assessment program that includes other standardized tests, assessment tools, alumni surveys, and placement data. The FE exam is particularly important because it is the only national test of upper-level engineering knowledge. The detailed reports of performance by subject area provide information that can help to evaluate a program's success in achieving the outcomes specified by ABET. Over time, these reports can also help programs document the effects of curriculum revisions, teaching innovations, and other actions taken to improve student mastery of engineering topics.

Based on experience, the authors conclude the following:

- Engineering programs should seriously consider using the FE exam subject-level performance data as part of their program assessment, with proper regard for the limitations described.
- A program will gain the most from the FE exam as an assessment tool if it requires all students to take the exam (particularly the discipline-specific PM exam), if faculty establish specific goals for their programs, and if the administration compares the program with peer institutions with similar requirements.
- Member boards (state licensing boards) should become proactive in working with academic programs to stress the use and value of the FE exam as an assessment tool.
- Institutions must remember that the primary purpose of the FE is to assess technical competencies. Other assessment tools need to be used to assess other outcomes, such as communication skill or preparation for independent learning.
- The results of each FE examination (Subject Matter Report) should be obtained directly by the institutions for their use in outcomes assessment.

REFERENCES

1. L. Fredericks Volkwein, Lisa R. Lattuca, Patrick T. Terenzini, Linda C. Strauss and Javzan Sukhbaatar, Engineering change: a study of the impact of EC 2000, *Int. J. Eng. Educ.*, **20**(3), 2004 pp. 318–328.
2. L. R. Lattuca, L. C. Strauss and J. F. Volkwein, Getting in sync: faculty and employer perceptions from the national study of EC 2000, *Proceedings of the Mudd Design Workshop V: Learning and Engineering Design*, Harvey Mudd College (2005).
3. N. Nirmalakhandan, D. Daniel and K. White, Use of subject-specific FE exam results in outcomes assessment, *Journal of Engineering Education*, **93**(1), 2004.
4. J. D. Bakos, Jr., Direct outcome-based assessment measures, *Journal of Professional Issues in Engineering Education and Practice*, **122**(1), 1996, pp. 31–34.
5. J. D. Bakos, Jr., Outcomes assessment: sharing responsibilities, *Journal of Professional Issues in Engineering Education and Practice,* **125**(3), 1999, pp. 108–111
6. R. B. Wicker, R. Quintana and A. Tarquin, evaluation model using fundamentals of engineering examinations, *Journal of Professional Issues in Engineering Education and Practice*, **125**(2), 1999, pp. 47–55.
7. William D. Lawson, Reliability and validity of FE exam scores for assessment of individual competence, program accreditation, and college performance, *Journal of Professional Issues in Engineering Education and Practice*, **133**(4), 2007, pp. 320–326.
8. NCEES website, http://www.ncees.org.
9. Walter LeFevre, John W. Steadman, Jill S. Tietjen, Kenneth R. White and David L. Whitman, Using the Fundamentals of Engineering (FE) examination to assess academic programs, NCEES White Paper (2005). Available from NCEES.

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