# **Using the Fundamentals of Engineering (FE) Examination** as an Outcomes Assessment Tool

**National Council of Examiners for Engineering and Surveying** | ncees.org

NCEES

# Using the Fundamentals of Engineering (FE) Examination as an Outcomes Assessment Tool

**B. Grant Crawford, Ph.D., P.E., F.ASEE**

**John W. Steadman, Ph.D., P.E., F.ASEE**

**David L. Whitman, Ph.D., P.E., F.ASEE**

**Rhonda K. Young, Ph.D., P.E.**

# About NCEES

The National Council of Examiners for Engineering and Surveying is a nonprofit organization made up of engineering and surveying licensing boards from all U.S. states, the District of Columbia, Guam, the Northern Mariana Islands, Puerto Rico, and the U.S. Virgin Islands. Since its founding in 1920, NCEES has been committed to advancing licensure for engineers and surveyors in order to safeguard the health, safety, and welfare of the American public.

NCEES helps its member licensing boards carry out their duties to regulate the professions of engineering and surveying. It develops best-practice models for state licensure laws and regulations and promotes uniformity among the states. It develops and administers the exams used for engineering and surveying licensure throughout the country. It also provides services to help licensed engineers and surveyors practice their professions in other U.S. states and territories. For more information, visit http://ncees.org.

# 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 measure the effectiveness of higher education, or it may result from accreditation requirements, which are progressively becoming driven by accountability and benchmarking. Whatever the reason, institutions must find practical, objective ways to assess their programs.

# Assessment process

In engineering education, the ABET Engineering Criteria have required a system of evaluation that includes program educational objectives, student outcomes, an assessment process to collect data on student outcomes, and an evaluation process that shows how this data is used to improve the program. The evaluation process may, and usually does, contain both direct and indirect measures. Direct measures allow the examination or observation of student knowledge against a measurable norm. Indirect measures attempt to ascertain the value of the learning experience through methods that do not involve actual student performance related to a specific outcome. A disadvantage of indirect measures is that assumptions must be made regarding the results of activities such as exit interviews, focus groups, and questionnaires. Accordingly, direct measures of student outcomes provide important advantages in program assessment.

One effective tool for direct assessment of certain aspects of engineering education is the NCEES Fundamentals of Engineering (FE) examination. This exam, developed to measure minimum technical competence, is the first step in the professional licensing of engineers. It is a pass-fail exam taken by approximately 50,000 people each year, most of whom are college seniors or recent graduates. For licensing, the examinee is interested only in whether he or she passed or failed. For assessment purposes, however, the pass-fail rate is of secondary importance, and the focus is instead on examinees' performance in a given subject.

Effective assessment of academic programs requires a set of tools and processes to evaluate various aspects of education. If the tools are to have any value as benchmarks or have credibility on some objective basis, they should make it possible to compare the results over time. This is essential to the continuous improvement process, since determining the effect of curriculum or instructional changes on outcomes is critical. Assessment tools with this comparative value are particularly difficult to obtain. Methods such as evaluation of portfolios and student exit surveys lack uniformity.

# FE examination

As the only nationally normed exam 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 FE Chemical, Civil, Electrical and Computer, Environmental, Industrial and Systems, and Mechanical exams include topics from both lower- and upper-level courses that appear in most institutions' curricula. The FE Other Disciplines exam is also available for engineering majors that are outside the discipline-specific exams mentioned above. The topics included in the discipline-specific exams are determined via surveys that are sent to practitioners and educators. Specifications are appropriately adjusted every 6–8 years to reflect current practices. The FE exam specifications have been updated, are effective in July 2020, and are provided in the appendix.

FE exam results can be used as one measurement in the assessment of the following student outcomes included in ABET General Criterion 3: (1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics; (2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors; and (4) an ability to recognize ethical and professional responsiblities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal context. The use of FE exam results in a particular outcome area is dependent on the specific engineering discipline. The current exam specifications for that discipline should be reviewed to determine the appropriateness of fit. While NCEES recognizes that most questions on the FE exam do not represent "complex" engineering problems, the assessment of this outcome could and should include the assessment of basic engineering problems. To satisfy student outcome 1, programs must demonstrate that students can apply the principles of engineering, science, and mathematics. The FE exam does this.

Although the FE exam does provide one method of assessment, employing the exam as an assessment tool has both advantages and disadvantages; therefore, its widespread use in outcomes assessment should be analyzed carefully. The exam should not, for example, be used to determine the curricular content of any program. Its purpose is to test competency for licensure; it is not intended to force programs to be similar. 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 across the exam as a whole.

One potential error in using the FE exam results as an assessment tool is focusing on the percentage of students who pass the exam. This criterion is too broad to be effective in improving instruction in specific topics; 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. In such a situation, the focus becomes "teaching to the exam" and not truly assessing how well students have learned the subject matter in the curriculum.

# Using the FE exam as an assessment tool

To properly use the FE exam as an assessment tool, the department or program faculty should first determine what topics they already emphasize in their program. This is a major part of the program educational objectives and student outcomes set by each program as required by ABET. After establishing the topics to be emphasized, 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 represent the entire population of graduates from the program. Many institutions that currently use the FE exam as one of their assessment tools require that all seniors take the exam and give a good-faith effort (but not necessarily pass).

Analysis of FE examinees over a number of test administrations has revealed that very few students fail to take the exam seriously. However, getting students to review materials before the exam, to prepare adequately, and ultimately to do their best work are legitimate concerns. Often, students do not lack motivation but instead struggle to make time for review in a crowded senior year (e.g., advanced coursework, capstone design, outside work commitments). Faculty who have doubts about whether students are putting forth their best efforts should take steps to motivate them, such as informing them of the importance of the results to their future or providing an incentive to pass the exam. Some programs that require all students to take the exam but do not require a passing score for graduation (the process recommended by the authors) offer an incentive to do well, such as reimbursing a portion of the cost of the exam to students who pass and also providing review sessions on topics pertinent to the exam.

Clearly, if the results are to be useful for outcomes assessment, the students must perform in a way that accurately reflects their understanding. It should be noted that when developing the Subject Matter Report (to be discussed later), NCEES works with psychometricians to remove random guessers so that assessment is not influenced by examinees who simply guess rather than attempt to correctly answer the exam questions.

Additionally, students should carefully consider when to take the FE exam during their senior year. For example, if they take it too soon, they may miss out on the benefit of course material covered during their final semester. With the computer-based format, students can schedule their appointment to take the FE exam up to one year before the test date. This makes it possible for them to book an exam appointment that accommodates completing particular coursework before taking the exam.

# FE exam topic coverage

To effectively use the FE exam as an assessment tool, faculty should know the specifications for the exam as well as the level of understanding that the items are meant to measure. Specifications for the various discipline-specific exams are provided in the appendix. As mentioned earlier, periodic changes to the specifications are based in large part on faculty and industry feedback to NCEES surveys. The goal is to ensure that the exam aligns with topics that are important to and current with what is being practiced in a specific engineering discipline.

In addition, assessments will be more meaningful if students take the FE exam matching their engineering discipline, which addresses topics that are germane to that discipline, rather than the FE Other Disciplines exam, which covers a broader range of topics. Furthermore, NCEES exam data indicate that students typically perform better on the discipline-specific exam most closely aligned to their major. For disciplines that are not represented with a discipline-specific exam, the FE Other Disciplines exam will provide information on topics that are relevant to most programs.

# CBT format of the FE exam

The FE exam is administered via computer-based testing (CBT). Examinees register for the exam through NCEES, obtaining approval to test from the appropriate state licensing board as required, and take the exam at any approved Pearson test center at a time and day that is convenient to them. Examinees receive their results (pass or fail) 7–10 days after taking the exam. These results are reported to the appropriate licensing board so that the examinees can be considered for engineer intern status. In January and July of each calendar year, NCEES produces and distributes detailed Subject Matter Reports containing results by topic area for examinees from each institution for the previous six-month period (January–June or July–December).

# FE exam results

The NCEES Subject Matter Report shown as Table 1 summarizes data on examinees who are from an EAC/ABET-accredited program who took one of the seven discipline-specific FE exams within ±12 months of graduation. This is the statistical group that should be used as a measure of program outcomes. Results are presented for examinees from a particular program and for examinees from ABET-accredited programs who declared the same major and who chose the same discipline-specific exam. As discussed later, this allows the institution's faculty the ability to compare their students' performance against all accredited examinees. The CBT form of the Subject Matter Report scales the raw scores for each subject on a 0–15 scale rather than as percentage correct. This is necessary because each CBT examinee will have different questions in a particular subject and the difficulty of that set of questions will be different from any other examinee's set of questions. A statistical method is used to equilibrate each examinee's set of questions so that comparable averages (the institution's and the accredited comparator) may be obtained. Comparator standard deviations will also be computed on this 0–15 scale.

## **Table 1.** Subject Matter Report for Institution X
## NCEES Fundamentals of Engineering examination
## ABET-accredited programs

**Examination:** Fundamentals of Engineering (FE)
**Report title:** Subject Matter Report by Major and Examination
**Exams administered:** Jul 01–Dec 31, 20XX
**Examinees included:** First-Time Examinees from EAC/ABET-Accredited Engineering Programs
**Graduation date:** Examinees Testing within 12 months of Graduation Date

| | | | |
|---|---|---|---|
| Name of Institution: | **Institution X** | | |
| Major: | **Civil** | FE Examination: | **Civil** |

| | Institution | ABET Comparator[2] |
|---|---|---|
| No. Examinees Taking[1] | 31 | 2,499 |
| No. Examinees Passing | 26 | 1,760 |
| Percent Examinees Passing | 84% | 70% |

| Uncertainty Range for Scaled Score[4] |
|---|
| ± 0.18 |

| | Number of Exam Questions | Institution Average Performance Index[3] | ABET Comparator Average Performance Index | ABET Comparator Standard Deviation | Ratio Score[4] | Scaled Score[4] |
|---|---|---|---|---|---|---|
| Mathematics and Statistics | 8 | 9.8 | 9.8 | 2.7 | 1.00 | 0.00 |
| Ethics and Professional Practice | 4 | 10.4 | 10.1 | 3.5 | 1.03 | 0.09 |
| Engineering Economics | 5 | 10.2 | 9.9 | 3.7 | 1.03 | 0.08 |
| Statics | 8 | 12.3 | 11.1 | 3.8 | 1.11 | 0.32 |
| Dynamics | 4 | 10.7 | 10.1 | 3.6 | 1.06 | 0.17 |
| Mechanics of Materials | 7 | 10.7 | 9.5 | 2.8 | 1.14 | 0.43 |
| Materials | 5 | 10.9 | 10.3 | 3.6 | 1.06 | 0.17 |
| Fluid Mechanics | 6 | 9.7 | 9.7 | 2.5 | 1.00 | 0.00 |
| Surveying | 6 | 8.7 | 9.2 | 3.1 | 0.95 | -0.16 |
| Water Resources and Environmental Engineering | 10 | 10.5 | 10.9 | 3.4 | 0.96 | -0.12 |
| Structural Engineering | 10 | 9.7 | 9.4 | 2.2 | 1.03 | 0.14 |
| Geotechnical Engineering | 10 | 9.5 | 9.4 | 2.1 | 1.01 | 0.05 |
| Transportation Engineering | 9 | 9.2 | 9.0 | 2.2 | 1.02 | 0.09 |
| Construction Engineering | 8 | 11.5 | 9.5 | 3.7 | 1.21 | 0.54 |

1. **0** examinees have been removed from this data because they were flagged as a random guesser.
2. Comparator includes all examinees from programs accredited by the ABET commission noted.
3. Performance index is based on a 0–15 scale.
4. These scores are made available for assessment purposes. See the NCEES publication entitled Using the FE as an Outcomes Assessment Tool at https://ncees.org/engineering/educator-resources/.

# Application of FE exam results

Prior to using the exam for assessment purposes, faculty should determine the expected performance in each topic area, depending on the emphasis of that topic in their program. For example, if a civil engineering program places little emphasis on surveying or transportation, students should be expected to perform accordingly. Conversely, if the program has a strong emphasis on structural engineering, one would expect a much higher performance in this area compared to the comparator average. For more conclusive results, faculty should also consider longitudinal performance over time rather than results from one Subject Matter Report. 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 two methods described in this paper are as follows:

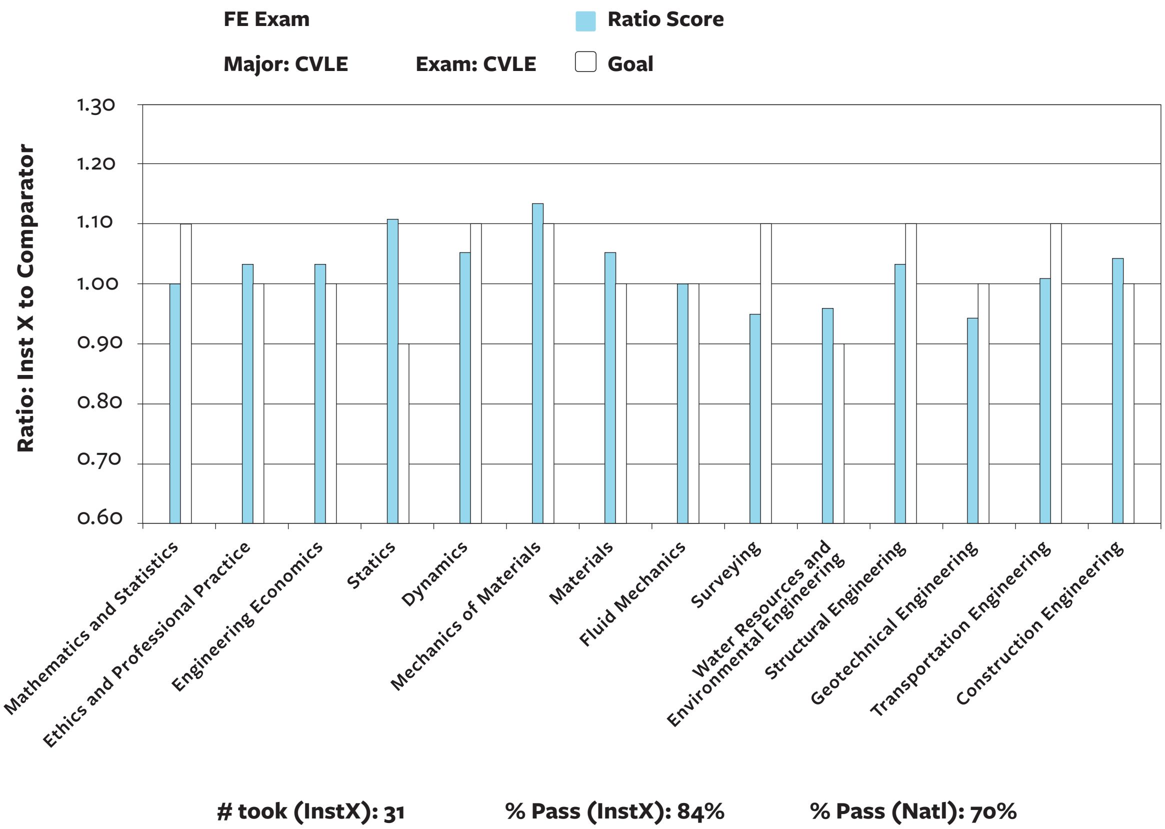
- Ratio method
- Scaled score method

# Ratio method

A simple and effective process for evaluating exam results is to compare the institution's results with comparator averages by topic in a simple ratio. For this method, the ratio of the performance at Institution X to the comparator performance is calculated for each topic area emphasized in Institution X's program. The faculty can develop appropriate expectations on this scale, determining how much above or below the comparator average is acceptable for their students. These expectation levels should be reasonable (remember that comparisons are between same majors taking the same discipline-specific exam) and, at the same time, should represent how the institution views its particular strengths. An expectation of 1.0 is certainly reasonable for most topics, while expectations of 1.05 to 1.10 might be reasonable on subjects that the institution believes are its strengths.

Figure 1 shows the ratio scores for a particular Subject Matter Report. This type of figure can provide a quick check on how the most recent students performed on each topic within the exam. It also demonstrates why one should not use the pass rate of the exam as an assessment tool. Note that the pass rate of civil engineering students at ABET-accredited Institution X is above the comparator pass rate for all civil engineering students from ABET-accredited institutions. However, the students are performing below the faculty's expectations on many of the individual topic areas.

**Figure 1.** **Ratio scores for a particular Subject Matter Report**




For assessment purposes, it is more informative to graph the performance on individual topics over time. Figures 2 and 3 show such graphs for student performance in two areas emphasized by Institution X.

**Figure 2.** **Longitudinal study of Institution X's performance in Probability and Statistics**

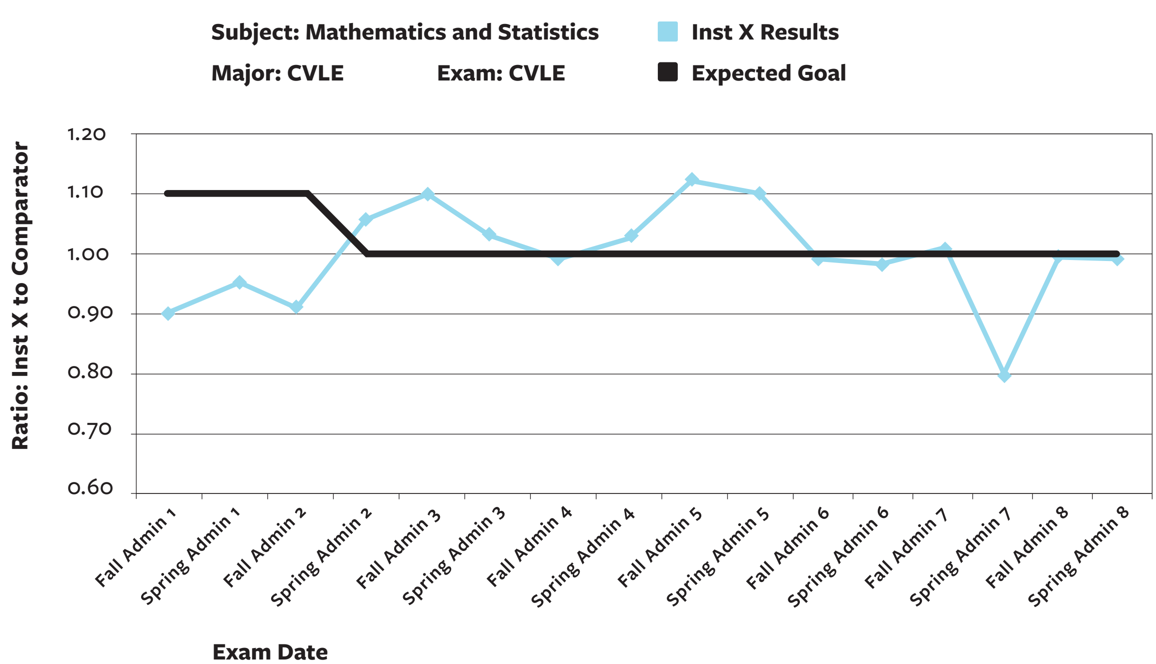
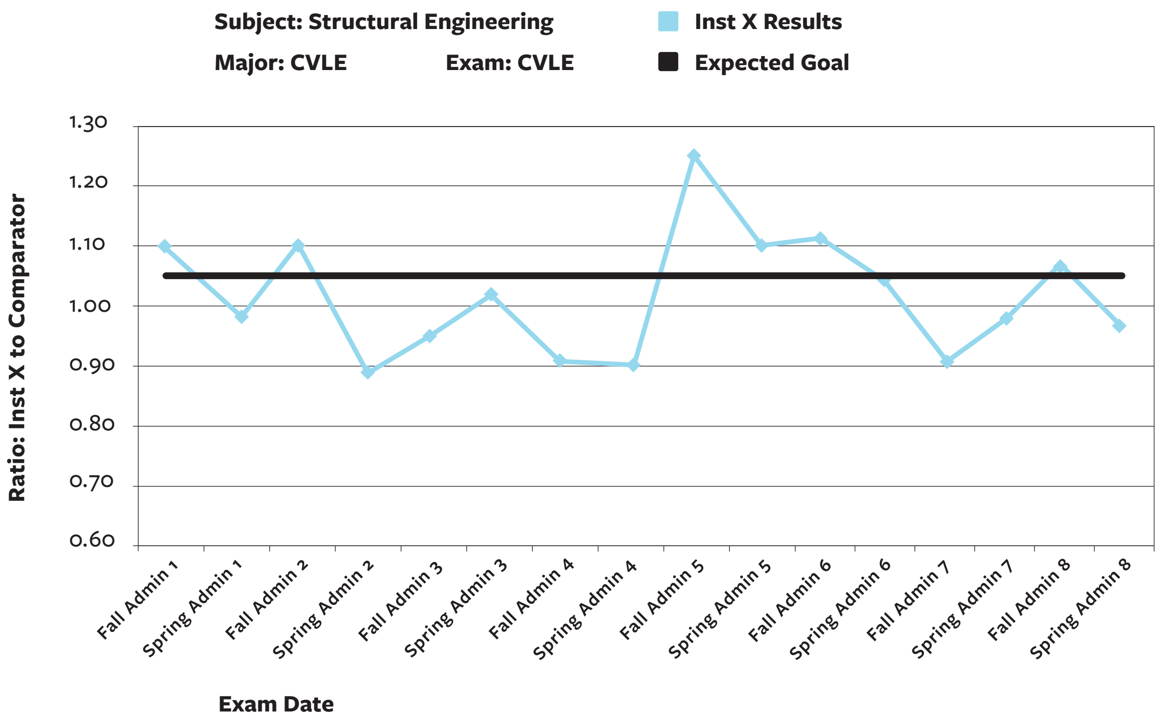


**Figure 3.** **Longitudinal study of Institution X's performance in Structural Engineering**




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

- Institution X initially assumed that its civil engineering students should score 10 percent higher in Mathematics and Statistics than the comparator average for civil engineering students. (Recall that the Subject Matter Report provides only comparator performance data for students in the same major.) The authors would argue, however, that this is a somewhat lofty and perhaps unobtainable goal for Institution X since the level of coverage in this topic does not vary much from institution to institution.

- After three exam administrations below the expectation level for Mathematics and Statistics, the faculty made two modifications. The first was a reexamination of the goal described above. Given that Institution X's students have no additional coursework in this subject beyond what would normally be taught elsewhere, the faculty adjusted their expectation and set a new goal for their students to meet the comparator average for this subject. This type of "close the loop" feedback is certainly acceptable. It also appears that some modification was made to the curriculum (such as a change in instructor, textbook, or course design), since the ratios since Spring Admin 2 have been very near or above the faculty expectation level except for one exam administration in Spring Admin 7.

- For Structural Engineering (Figure 3), note that Institution X has an expectation that its students perform at a ratio of 1.05. This is due to the fact that it emphasizes this subject material and perhaps requires the students to take more structural analysis courses than would be expected at other institutions. The performance on this subject is sporadic, with ratios above 1.25 and as low as 0.88. One possible explanation for this irregular performance is the small number of students who take any one particular exam. This can be accounted for in the scaled score approach discussed next. This type of performance also points out a suggestion that is made by the authors: put the subject matter on a watch list if it falls below the expected goal for two consecutive exam administrations, but do not attempt a curricular change in a subject matter area unless the students' performance has been below the expected goal for three consecutive exam administrations.

# Scaled score method

The concept of the scaled score method was developed to assist institutions that have a relatively small number of examinees during each reporting period. This method requires the use of the standard deviation of the examinees' results for each topic. In the CBT Subject Matter Report, the standard deviation is based on the 0–15 Performance Index scale discussed earlier. Standard deviation of the Performance Index may be relatively high in specification topics that have few questions (standard deviation may range above 5).

The scaled score was developed to allow institutions 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 to the percentage above or below the comparator average given by the ratio method)

- Allow a range of uncertainty in the institution's performance to account for small numbers of examinees

The scaled score is defined as follows:

$$\text{Scaled score} = \frac{\mathit{PI\ for\ Univ\ X} - \mathit{PI\ comparator}}{\mathit{PI\ comparator\ standard\ deviation}}$$

*PI* = Performance Index

The range of uncertainty comes from the following derivation.

From the concept of confidence interval on a mean:

The mean of a population ($\mu$) is related to the mean of a sample size $n$ ($\bar{x}$) by

$$\bar{x} - Z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \le \mu \le \bar{x} + Z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$$

where $Z_{\alpha/2}$ relates to the desired double-sided confidence interval given by $\alpha$. The value can be determined from the unit normal distribution table for any given value of $\alpha$.

Thus, the confidence interval on $\mu$ is $\pm Z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$

Let $Y_{Univ\ X} = \bar{x}_{Univ\ X} \pm Z_{\alpha/2}\frac{\sigma_{Univ\ X}}{\sqrt{n_{Univ\ X}}}$

$$Y_{Univ\ X} - \bar{x}_{Comp} = \bar{x}_{Univ\ X} - \bar{x}_{Comp} \pm Z_{\alpha/2}\frac{\sigma_{Univ\ X}}{\sqrt{n_{Univ\ X}}}.$$

Since NCEES does not provide standard deviation data for individual institutions, it will be assumed that the comparator standard deviation can be substituted for the institution's standard deviation. In that case,

$$\frac{Y_{Univ\ X} - \bar{x}_{Comp}}{\sigma_{Comp}} = \frac{\bar{x}_{Univ\ X} - \bar{x}_{Comp}}{\sigma_{Comp}} \pm \frac{Z_{\alpha/2}}{\sqrt{n_{Univ\ X}}}.$$

Normally, for a 99 percent confidence interval $Z_{\alpha/2}$ would be 2.58. However, in this case, the uncertainty would be so large that the analysis results (see below) for all subjects would indicate that no action needs to be considered. The authors feel that this is unreasonable and suggest using a value of $Z_{\alpha/2} = 1.0$. This allows a reasonable amount of uncertainty based on the number of students taking the exam at any specific institution.

The scaled score is defined as follows:

$$\text{Scaled score } = \frac{\textit{PI for Univ X} \quad - \textit{PI comparator}}{\textit{PI comparator standard deviation}}.$$

and the range of uncertainly for the scaled score is

$$\pm \frac{1}{\sqrt{\# \; of \; takers \; at \; Univ \; X}}.$$

Generally, it is more common for faculty to set student goals (expectations) based on the ratio score rather than on the number of standard deviations above the national average. As shown below, there is a mathematical relationship between the ratio goal and the scaled score goal. Thus, the ratio goal can be used to estimate an associated scaled score goal.

The scaled score can be rearranged as

$$Scaled\ score = \frac{\bar{x}_{Comp}}{\sigma}(ratio\ score - 1).$$

In that case, the scaled score goal is then related to the ratio goal as

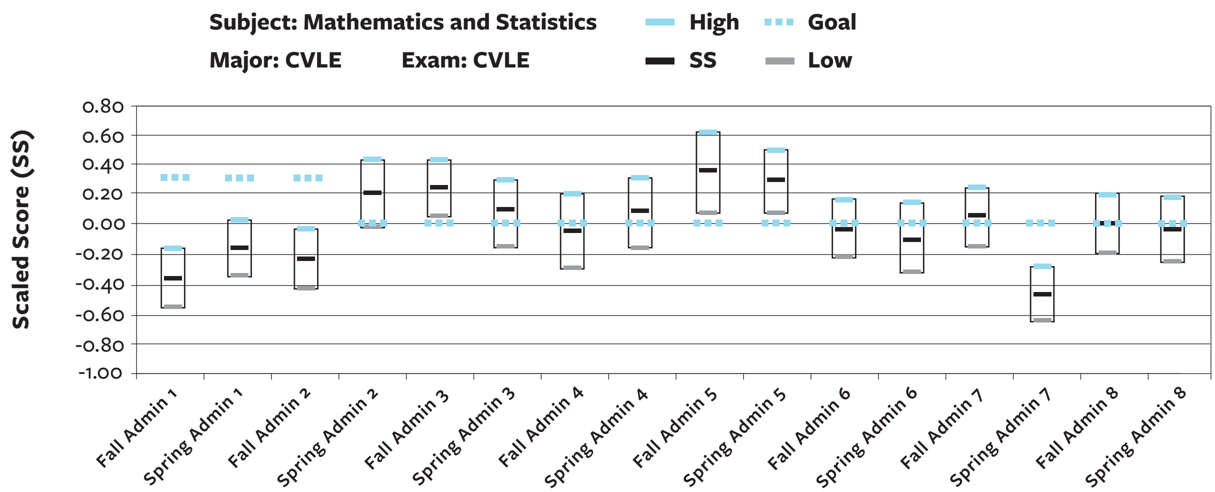
$$Scaled\ score\ goal = \frac{\bar{x}_{Comp}}{\sigma}(ratio\ score\ goal - 1).$$

Unfortunately, the term $\frac{\bar{x}_{Comp}}{\sigma}$ depends on each subject as well as the results of each exam administration. The value of this term generally ranges between 2 and 4. The authors suggest using an average value of 3 to convert a ratio goal to an associated scaled score goal. That is, if the ratio goal is 1.05, the associated scaled score goal would be 0.15.

As discussed in the section on ratio scores, the authors suggest that an institution put the subject matter on a watch list if it falls below the expected goal for two consecutive exam administrations but not attempt a curricular change in a subject matter area unless the students' performance has been below the expected goal for three consecutive exam administrations.

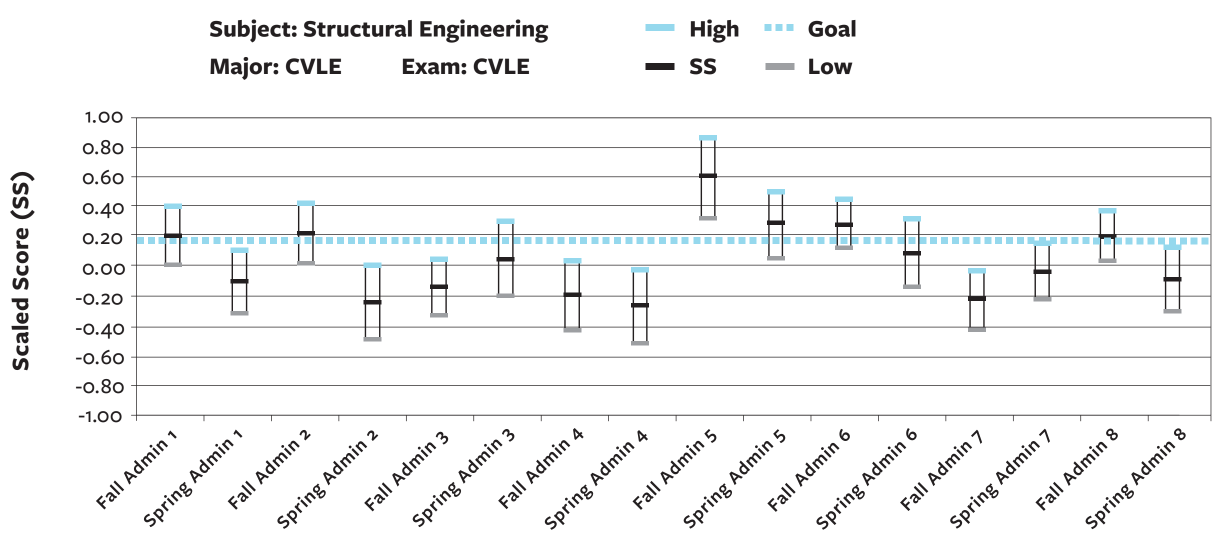
For the same topics previously discussed, the scaled score graphs are shown on the facing page.

**Figure 4.** Scaled score results for Institution X's performance in Mathematics and Statistics




For Mathematics and Statistics (shown in Figure 4), a ratio goal of 1.1 translated to a scaled score goal of 0.30, and a ratio goal of 1.0 translated to a scaled score goal of 0.0. After the reduction in expectation that occurred for the Spring Admin 2 exam administration, one can see that, within the range of uncertainty provided by this analysis method, the institution has scored at or above the expectation level for all exam administrations except for Spring Admin 7.

**Figure 5.** Scaled score results for Institution X's performance in Structural Engineering




For Structural Engineering (shown in Figure 5), a ratio goal of 1.05 translated to a scaled score goal of 0.15. Using the ratio method, the students' performance fell below the expected goal for five consecutive exam administrations (Spring Admin 2 through Spring Admin 4). However, using the scaled score approach, the goal was reached for Spring Admin 3, which indicated that this subject should have simply remained on the watch list. Subsequent results seem to indicate that the students are, once again, achieving at the expected level, with only a couple of single points below the expectation level (Fall Admin 7 and Spring Admin 8).

# Academic Year Averaging

Academic year averaging could be used (instead of showing each fall and spring administration) for at least three reasons: to measure the performance of the entire senior class as a single data point; to smooth out the performance if there are dramatic differences between fall and spring administrations (which might be especially true for subjects that are taught late in the curriculum); and to reduce the uncertainty if using the Scaled Score Method (especially if there are 10 or fewer examinees during either the fall or spring administration).

Using a spreadsheet and the detailed information supplied by the Subject Matter Report shown in Table 1, the following calculations can be made:

- The Weight-Averaged PI for each subject is calculated for both the Institution and the ABET Comparator as:

$$Average\ PI = \frac{n_{fall}\, PI_{fall} + n_{spring}\, PI_{spring}}{n_{fall} + n_{spring}}$$

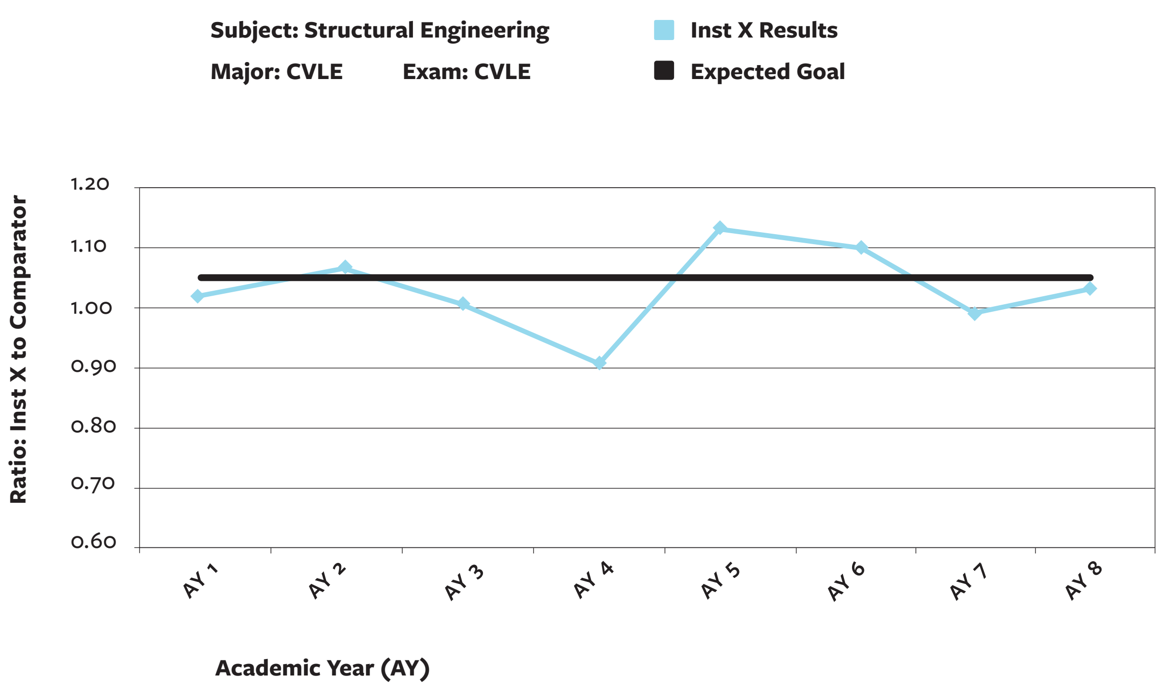
- The Weight-Averaged Standard Deviation for each subject is calculated as:

$$Average\ \sigma = \sqrt{\frac{n_{fall}\, \sigma^2_{fall} + n_{spring}\, \sigma^2_{spring}}{n_{fall} + n_{spring}}}$$

Using the previous definitions, the Ratio Score and the Scaled Score can be calculated for each subject for each academic year.

This is shown in Figure 6 for the structural engineering topic that was originally shown for each semester in Figure 3. When using academic year averaging, the authors would suggest that a subject should go on the program's watch list if it falls below the expected goal for one academic year, but that a curricular change in a subject matter area should not be attempted unless the students' performance has been below the expected goal for two consecutive academic years. For the subject shown here, it appears that the program has failed to meet its goal during AY 7 and AY 8 and, thus, some curricular change should be expected.

**Figure 6.** **Academic year averaging**



Two additional examples are provided below in Figures 7 and 8 for the electromagnetics topic for electrical engineering students. Figure 7 shows—using the Ratio method—that it is difficult to determine whether or not this institution's students have met (or not met) the desired goal in academic years 5 and 7 due to the severe oscillation in their performance between the fall and spring semesters. Once academic averaging is utilized, the data is properly smoothed, and one can make a determination that the students actually succeeded in meeting the desired goal for both AY 5 and AY 7.

**Figure 7.** Academic Year Averaging

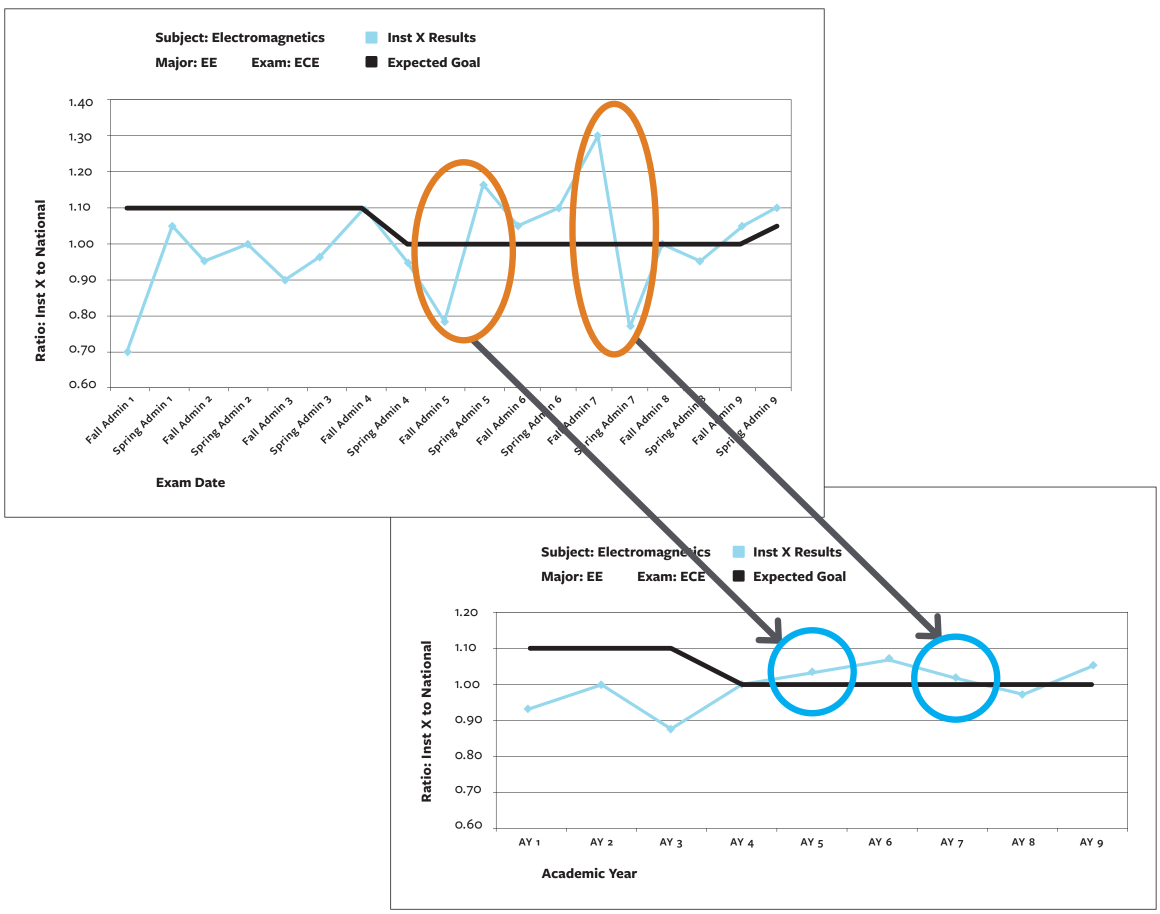
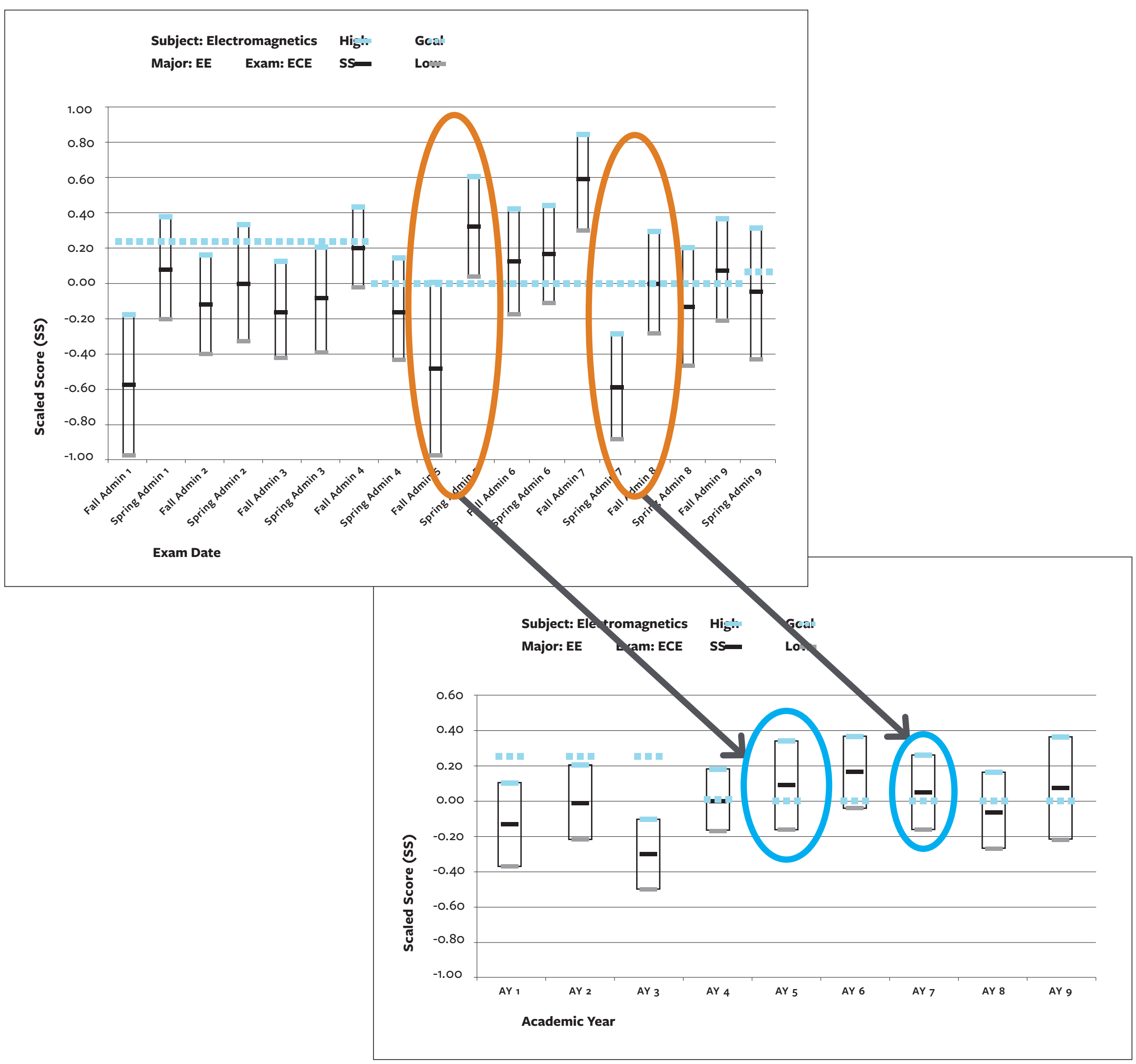


Figure 8 shows the same information utilizing the Scaled Score method. Even within the uncertainty bar associated with the scaled score, it again is difficult to see whether or not this institution's students have met (or not met) the desired goal due in academic years 5 and 7 due to the severe oscillation in their performance between the fall and spring semesters. Once academic averaging is utilized, the data is not only properly smoothed, but the size of the uncertainty bar decreases substantially, thus giving the institution a higher degree of confidence that its students actually succeeded in meeting the desired goal for both AY 5 and AY 7.

**Figure 8.** Academic Year Averaging



# Other issues

In making an assessment using the FE exam results, faculty must also consider that some students may not have completed 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 exam before taking that course will not be prepared for that subject area.

Effective assessment should result in continuous program improvement. Faculty should evaluate the results of student performance in individual subject areas. Doing so will identify areas in which students are performing below the goals established by the faculty and perhaps significantly below national averages. Evaluations should initiate 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 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 exam administrations 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 exam administrations should be considered and the exam content compared to the course content.

One challenge with using the FE exam for outcomes assessment is that at many institutions, not all engineering students take the FE exam. Thus, the institution has a self-selected sample that will, most likely, contain a higher percentage of the best and most motivated students. Evaluation of FE exam results for this situation can still be useful (a) if one assumes that the characteristics of the self-selecting group stay relatively constant from time frame to time frame and (b) if the evaluator looks at the trend of either the ratio score or the scaled score over time in addition to the student expectations set by the faculty. That is, the ratio or scaled score of a particular topic may always be exceeding the faculty expectation, but the ratio or scaled scores may be declining with time. This situation would be considered one in which curricular changes should be instituted to arrest the decline.

# Conclusions

After much 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 nationally normed test of lower- and 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 student 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 their 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 caveats described.
- A program will gain the most from using the FE exam as an assessment tool if it requires all students to take the exam, particularly the appropriate discipline-specific exam, and if faculty establish specific goals for the program.
- State licensing boards should be 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 exam is to assess minimal technical competence. Other assessment tools need to be used to assess higher-level theories or critical thought that might be the focus of some portion of an institution's program.

# Appendix

## FE exam specifications effective beginning with the July 2020 examinations

Listed below are the topics that the exams cover and the range of the number of questions in each topic area. Examinees have 6 hours to complete the exam, which contains 110 multiple-choice questions. The 6-hour time also includes a tutorial, a break, and a brief survey at the conclusion.

### Chemical

| Topic | No. of Questions | Topic | No. of Questions |
|---|---|---|---|
| Mathematics | 6–9 | Mass Transfer and Separation | 8–12 |
| Probability and Statistics | 4–6 | Solids Handling | 3–5 |
| Engineering Sciences | 4–6 | Chemical Reaction Engineering | 7–11 |
| Materials Science | 4–6 | Economics | 4–6 |
| Chemistry and Biology | 7–11 | Process Design | 7–11 |
| Fluid Mechanics/Dynamics | 8–12 | Process Control | 4–6 |
| Thermodynamics | 8–12 | Safety, Health, and Environment | 5–8 |
| Material/Energy Balances | 10–15 | Ethics and Professional Practice | 3–5 |
| Heat Transfer | 8–12 | | |

### Civil

| Topic | No. of Questions | Topic | No. of Questions |
|---|---|---|---|
| Mathematics and Statistics | 8–12 | Surveying | 6–9 |
| Ethics and Professional Practice | 4–6 | Water Resources and Environmental Engineering | 10–15 |
| Engineering Economics | 5–8 | Structural Engineering | 10–15 |
| Statics | 8–12 | Geotechnical Engineering | 10–15 |
| Dynamics | 4–6 | Transportation Engineering | 9–14 |
| Mechanics of Materials | 7–11 | Construction Engineering | 8–12 |
| Materials | 5–8 | | |
| Fluid Mechanics | 6–9 | | |

### Electrical and Computer

| Topic | No. of Questions | Topic | No. of Questions |
|---|---|---|---|
| Mathematics | 11–17 | Electronics | 7–11 |
| Probability and Statistics | 4–6 | Power Systems | 8–12 |
| Ethics and Professional Practice | 4–6 | Electromagnetics | 4–6 |
| Engineering Economics | 5–8 | Control Systems | 6–9 |
| Properties of Electrical Materials | 4–6 | Communications | 5–8 |
| Circuit Analysis (DC and AC Steady State) | 11–17 | Computer Networks | 4–6 |
| Linear Systems | 5–8 | Digital Systems | 8–12 |
| Signal Processing | 5–8 | Computer Systems | 5–8 |
| | | Software Engineering | 4–6 |

### Environmental

| Topic | No. of Questions |
|---|---|
| Mathematics | 5–8 |
| Probability and Statistics | 4–6 |
| Ethics and Professional Practice | 5–8 |
| Engineering Economics | 5–8 |
| Fundamental Principles | 7–11 |
| Environmental Chemistry | 7–11 |
| Health Hazards and Risk Assessment | 4–6 |
| Fluid Mechanics and Hydraulics | 12–18 |
| Thermodynamics | 3–5 |
| Surface Water Resources and Hydrology | 9–14 |
| Groundwater, Soils, and Sediments | 8–12 |
| Water and Wastewater | 12–18 |
| Air Quality and Control | 8–12 |
| Solid and Hazardous Waste | 7–11 |
| Energy and Environment | 4–6 |

### Industrial and Systems

| Topic | No. of Questions |
|---|---|
| Mathematics | 6–9 |
| Engineering Sciences | 4–6 |
| Ethics and Professional Practice | 4–6 |
| Engineering Economics | 9–14 |
| Probability and Statistics | 10–15 |
| Modeling and Quantitative Analysis | 9–14 |
| Engineering Management | 8–12 |
| Manufacturing, Service, and Other Production Systems | 9–14 |
| Facilities and Supply Chain | 9–14 |
| Human Factors, Ergonomics, and Safety | 8–12 |
| Work Design | 7–11 |
| Quality | 9–14 |
| Systems Engineering, Analysis, and Design | 8–12 |

### Mechanical

| Topic | No. of Questions |
|---|---|
| Mathematics | 6–9 |
| Probability and Statistics | 4–6 |
| Ethics and Professional Practice | 4–6 |
| Engineering Economics | 4–6 |
| Electricity and Magnetism | 5–8 |
| Statics | 9–14 |
| Dynamics, Kinematics, and Vibrations | 10–15 |
| Mechanics of Materials | 9–14 |
| Material Properties and Processing | 7–11 |
| Fluid Mechanics | 10–15 |
| Thermodynamics | 10–15 |
| Heat Transfer | 7–11 |
| Measurements, Instrumentation, and Controls | 5–8 |
| Mechanical Design and Analysis | 10–15 |

### Other Disciplines

| Topic | No. of Questions |
|---|---|
| Mathematics | 8–12 |
| Probability and Statistics | 6–9 |
| Chemistry | 5–8 |
| Instrumentation and Controls | 4–6 |
| Engineering Ethics and Societal Impacts | 5–8 |
| Safety, Health, and Environment | 6–9 |
| Engineering Economics | 6–9 |
| Statics | 9–14 |
| Dynamics | 9–14 |
| Strength of Materials | 9–14 |
| Materials | 6–9 |
| Fluid Mechanics | 12–18 |
| Basic Electrical Engineering | 6–9 |
| Thermodynamics and Heat Transfer | 9–14 |

# Report Authors

## B. Grant Crawford, Ph.D., P.E., F.ASEE

Grant Crawford is professor of mechanical engineering at Quinnipiac University. He has served on the NCEES FE exam committee since 2005 and is an active member of the engineering education community, having served on the ASEE Board of Directors three times. He has been involved in and led ABET accreditation and assessment at the program level for over 14 years. He is an EAC PEV and ETAC Commissioner for ABET.

## John W. Steadman, Ph.D., P.E., F.ASEE

John W. Steadman is dean of the University of South Alabama College of Engineering. He also taught at the University of Wyoming for 32 years, 14 of which he was head of the electrical and computer engineering department. He is a past president of NCEES and IEEE-USA and an emeritus member of the Wyoming Board of Registration for Professional Engineers and Professional Land Surveyors. He has served on NCEES exam committees since 1986.

## David L. Whitman, Ph.D., P.E., F.ASEE

David L. Whitman is Professor Emeritus at the University of Wyoming. He is a past president of NCEES and an emeritus member of the Wyoming State Board of Registration for Professional Engineers and Professional Land Surveyors. He has been involved with various NCEES committees and has been part of the FE exam preparation since 2001.

## Rhonda K. Young, Ph.D., P.E.

Rhonda K. Young is professor and chair of civil engineering at Gonzaga University. She has served on the NCEES FE exam committee since 2005 and is an active member of the transportation engineering education community. She has been involved in ABET accreditation and assessment at the department level for over 15 years.

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