Supplementing FE Exam Results for Continuous Assessment

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Concurrent with the development of specific program outcomes for ABET review, it is necessary to identify assessment vehicles for each stated outcome. One attractive assessment characteristic is the ability to compare student performance from a specified department at the home institution to that of other students in the state and in the nation in a similar department. Ohio University's Civil Engineering (OUCE) faculty identified the Fundamentals of Engineering (FE) Exam as one opportunity to make such comparisons. The appropriateness of using the FE Exam arises due to the broad coverage of core engineering topics, as well as specific upper level topics addressed in discipline specific afternoon sections. The current level of data reporting by the National Council of Examiners for Engineering and Surveying (NCEES) allows comparison of departmental results on each section of the exam with statewide and national averages, or by Carnegie institutional classification.

Core engineering topics covered in the morning session of the FE include chemistry, computers, dynamics, electrical circuits, engineering economics, ethics, fluid mechanics, material science/structure of matter, mathematics, mechanics of materials, statics, and thermodynamics. With the advent of the discipline specific afternoon component in the exam in 1997, an additional level of assessment could be made in core courses specific to the civil engineering discipline. Afternoon sections in the civil engineering discipline specific exam include; computer and numerical methods, construction management, environmental engineering, hydraulics and hydrologic systems, legal and professional aspects, soil mechanics and foundations, structural analysis, structural design, surveying, transportation facilities, water purification and treatment.

While this assessment vehicle can be a valuable part of an overall assessment plan, there are limitations associated with a tool that evaluates the minimum competencies of engineering graduates only once in an educational process that occurs at the end of the students' tenure. This 'end of program' assessment may help identify topical weaknesses, however the ability to make curricular modifications to strengthen these skills works on a schedule that parallels a student's academic tenure, usually 4 to 5 years. This obviously hinders the ability to make adjustments and assess those changes promptly within a single ABET review cycle, even if a 6-year Next General Review (NGR) outcome is achieved.

To address this challenge, OUCE has instituted a policy of testing the minimum competencies of each student in each of the departmental courses offered throughout the year. This assessment technique, termed the Prerequisite Inventory (PI), consists of a quiz administered within the first few days of class each quarter. The quiz contains FE style questions identified by topic area as expected prerequisite knowledge specific to each course. The results are used to identify, on a

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quarterly basis, any program concerns with the intent of addressing small problems quickly and making curricular adjustments prior to the students graduating from the program.

One of the major challenges of implementing the PI as an assessment device was the need to assure that the majority of FE topics were assessed. It was readily noted that all FE topics could not be assessed, as some of the covered material occurs in courses at the end of a sequence or in the senior year and, therefore, cannot be assessed by a subsequent course. However, this topical material would be assessed on the FE and the results would be available within the following academic year. Additionally, a single topic on the FE may have several subtopics that may require individual assessment. For example, the mathematics topic could cover subtopics such as algebra, calculus, complex numbers, differential equations, geometry, linear algebra, probability and statistics, trigonometry, and vectors.

To assure adequate coverage of each topic for students during each year of academic standing, a PI coverage matrix was developed to determine the topical coverage in each required and elective course for the morning and discipline specific afternoon sections of the FE Exam. These matrices were continuously updated and are presented in Tables 1 and 2 for the PIs administered from academic year (AY) 2000-2001 to date. Additionally, while it was acknowledged early in the development process that all subtopics of a specific topic could not be covered, PI questions were further categorized by subtopic and an effort was made to cover a variety of potentially testable subtopics. Subtopic coverage matrices were developed for those topics that were covered with the greatest frequency and include mathematics, chemistry, fluid mechanics, mechanics of materials, and statics. This information is presented in Tables 3 through 7.

Performance criteria are defined as the minimum levels of competency expected for a measured outcome. Three performance criteria based on the FE were established as general standards for all graduates, since all OUCE students are required to take the FE Exam. First, there is an expectation that the overall percentage of students receiving a passing grade will exceed the national average for the CE discipline. Second, regardless of the national average, it is expected that 80% of all students taking the FE will receive a passing grade. Third, for specific topical areas, student percent correct scores on each section of the FE was expected to exceed the national average percent correct score on those portions of the exam.

Two performance criteria were established for the PI. First, the percent correct score on the PI will exceed the percent correct score on the same (or equivalent) topic on the FE. Second, students are expected to demonstrate improvement with respect to the percentage of correct answers on the PI questions as they progress from sophomore through senior standing. This is evaluated by comparing average percent correct scores on all PI questions from 200 level, 300 level, and 400 level courses. Also, while physics and geology do not appear on the FE, they are included as prerequisites on two PIs. Students are expected to exceed a score of 60% on PI questions covering these topics, which is approximately the average percent correct score for all topics on the FE. All performance criteria for the FE and PI are summarized in Table 8.

While a detailed assessment of all PI results was conducted for use in the OUCE ABET Self Study Report, a complete analysis of all data collected is beyond the scope of this paper. This paper does compare some PI and FE results, evaluate student performance against the stated PI

Table 1. PI coverage matrix for the morning sections of the FE Exam for required (white) and elective (shaded) courses assessed Sp00 thru Sp04.	Chemistry	Computers	Dynamics	Electrical Circuits	Engineering Economics	Ethics	Fluid Mechanics	Material Sci. / Str Matter	Mathematics	Mechanics of Materials	Statics	Thermodynamics
CE 200 CE Fundamentals												
CE 201 CE Computational Techniques									X			
CE 210 Plane Surveying									X			
CE 220 Statics		X							X			
CE 222 Strength of Materials		X							X		X	
CE 311 Route Engineering												
CE 330 Structural Theory I		X							X	X	X	
CE 331 Structural Theory II									X	X	X	
CE 340 Fluid Mechanics			X						X		X	
CE 342 Applied Hydraulics							X					
CE 343 Hydrology							X		X			
CE 353 Basics of Environmental Engr.	X						X		X			
CE 361 Transportation Engineering												
CE 370 Geotechnical Engineering							X			X		
CE 380 CE Materials										X		
CE 400 Societal Concerns in CE		X				X			X			
CE 410 Applied Property Surveying												
CE 415 Geodetic Surveying												
CE 423 Continuum Mechanics									X			
CE 424 Strength of Materials II										X		
CE 432 Structural Design in Concrete		X								X	X	
CE 433 Structural Design in Steel		X							X	X	X	
CE 437 Timber Design		X							X	X	X	
CE 438 Prestressed Concrete Design										X		
CE 439 Computer-Aided Struct. Dsgn.											X	
CE 450 Water Treatment	X						X		X			
CE 451 Wastewater Treatment	X						X		X			
CE 452 Water & Wastewater Analysis	X											
CE 453 Solid/Hazardous Waste Mgmt.	X								X			
CE 462 Traffic Engineering												
CE 482 Paving Materials and Mixtures	X						X	X		X		
Number of Courses with PI Topic	**6**	**7**	**1**	**0**	**0**	**1**	**7**	**1**	**16**	**10**	**8**	**0**
Number of Questions on FE	**11**	**6**	**10**	**12**	**5**	**5**	**8**	**8**	**24**	**8**	**12**	**11**

Table 2. PI coverage matrix for CE afternoon sections of the FE Exam and miscellaneous topics for required (white) and elective (shaded) courses assessed Sp00 thru Sp04.

Course	Comp & Num Methods	Construction Management	Environmental Engineering	Hydraulics / Hydrol. Sys	Legal/Professional Aspects	Soil Mech & Foundations	Structural Analysis	Structural Design	Surveying	Transportation Facilities	Water Purification & Treat	Physics	Alignment/Curve Design	Geology
CE 200 CE Fundamentals														
CE 201 CE Comp. Techniques														
CE 210 Plane Surveying														
CE 220 Statics	X											X		
CE 222 Strength of Materials	X													
CE 311 Route Engineering									X					
CE 330 Structural Theory I	X													
CE 331 Structural Theory II							X							
CE 340 Fluid Mechanics														
CE 342 Applied Hydraulics														
CE 343 Hydrology														
CE 353 Basics of Environ. Engr.														
CE 361 Transportation Engr.													X	
CE 370 Geotechnical Engineering														X
CE 380 CE Materials														
CE 400 Societal Concerns in CE	X				X									
CE 410 Applied Prop. Surveying									X					
CE 415 Geodetic Surveying									X					
CE 423 Continuum Mechanics														
CE 424 Strength of Material II														
CE 432 Struct. Design in Concrete	X						X							
CE 433 Struct. Design in Steel	X						X							
CE 437 Timber Design	X						X							
CE 438 Prestressed Concrete Dsgn							X	X						
CE 439 Comp-Aided Struct. Dsgn.							X	X						
CE 450 Water Treatment				X		X								
CE 451 Wastewater Treatment				X										
CE 452 Water & Wastewater Anal.														
CE 453 Solid/Haz. Waste Mgmt.						X								
CE 462 Traffic Engineering										X				
CE 482 Paving Materials/Mixtures						X								
Number of Courses with PI Topic	**7**	**0**	**0**	**2**	**1**	**3**	**6**	**2**	**3**	**1**	**0**	**1**	**1**	**1**
Number of Questions on FE	**6**	**3**	**6**	**6**	**3**	**6**	**6**	**6**	**6**	**6**	**6**	**0**	**0**	**0**

Table 3. PI coverage matrix for mathematics sub-topics for required (white) and elective (shaded) courses identified in Table 1.	Algebra	Calculus & Integration	Differential Equations	Dot & Cross Products	Equation of a Line	Geometry & Distance	Logs & Exponentials	Probability & Statistics	Simul. Eqns. & Matrices	Trigonometry	Vectors
CE 201 CE Computational Techniques		X	X				X			X	
CE 210 Plane Surveying	X		X		X	X				X	
CE 220 Statics	X	X		X	X	X			X	X	X
CE 222 Strength of Materials	X	X									X
CE 330 Structural Theory I		X									X
CE 331 Structural Theory II									X		
CE 340 Fluid Mechanics		X	X	X			X				X
CE 343 Hydrology								X			
CE 353 Basics of Environ. Engineering	X	X	X			X				X	
CE 400 Societal Concerns in CE	X										
CE 423 Continuum Mechanics			X						X	X	
CE 433 Structural Design in Steel		X			X						
CE 437 Timber Design		X			X						
CE 450 Water Treatment			X				X				
CE 451 Wastewater Treatment		X					X				
CE 453 Solid & Hazardous Waste Mgmt.	X	X									
Total in required courses	**4**	**7**	**4**	**2**	**3**	**2**	**4**	**1**	**1**	**3**	**4**
Total in elective courses	**2**	**3**	**2**	**0**	**1**	**1**	**0**	**0**	**2**	**2**	**0**

Table 4. PI coverage matrix for chemistry sub-topics for required (white) and elective (shaded) courses identified in Table 1.	Atoms	Equilibrium	Gas Laws	Molecular Structure	Organic Chemistry	Oxidation State	Reactions & Kinetics	Solutions	Stoichiometry
CE 353 Basics of Environ. Engineering	X				X	X	X		X
CE 450 Water Treatment		X	X			X	X	X	X
CE 451 Wastewater Treatment		X			X		X		X
CE 452 Water & Wastewater Analysis		X					X	X	
CE 453 Solid & Hazardous Waste Mgmt.				X			X		X
CE 482 Paving Materials and Mixtures							X		
Total in required courses	**0**	**2**	**1**	**0**	**1**	**1**	**2**	**1**	**2**
Total in elective courses	**1**	**1**	**0**	**1**	**1**	**1**	**4**	**1**	**2**

Table 5. PI coverage matrix for fluid mechanics sub-topics for required (white) and elective (shaded) courses identified in Table 1.	Bernoulli & Energy	Buoyancy	Continuity & Momentum	Dimensionless Parameters	Flow Motion	Fluid Properties	Fluid Statics	Friction Losses	Lift & Drag	Open Channel	Pumps & Turbines
CE 342 Applied Hydraulics	X		X	X	X	X	X	X			X
CE 343 Hydrology	X				X	X	X		X		
CE 353 Basics of Environ. Engineering	X	X					X				
CE 370 Geotechnical Engineering	X				X	X					
CE 450 Water Treatment	X						X	X			X
CE 451 Wastewater Treatment	X	X	X		X			X		X	X
CE 482 Paving Materials & Mixtures		X									
Total in required courses	**5**	**1**	**2**	**1**	**4**	**3**	**3**	**3**	**1**	**1**	**3**
Total in elective courses	**1**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**

Table 6. PI coverage matrix for mechanics of materials sub-topics for required (white) and elective (shaded) courses identified in Table 1.	Axial Stress & Deformation	Bending, Buckling & Deflection	Combined Stress	Composite Bars & Beams	Material Properties	Mohr's Circle	Moment of Inertia	Stress & Strain	Yield
CE 330 Structural Theory I	X	X						X	
CE 331 Structural Theory II		X						X	
CE 370 Geotechnical Engineering					X	X		X	
CE 380 Civil Engineering Materials				X	X			X	
CE 424 Strength of Materials II	X	X				X			
CE 432 Structural Design in Concrete						X			
CE 433 Structural Design in Steel		X					X	X	X
CE 437 Timber Design		X	X				X	X	
CE 438 Prestressed Concrete Design			X						
CE 482 Paving Materials and Mixtures								X	
Total in required courses	**1**	**2**	**0**	**1**	**2**	**2**	**1**	**4**	**1**
Total in elective courses	**1**	**3**	**2**	**0**	**0**	**1**	**1**	**3**	**0**

Table 7. PI coverage matrix for statics sub-topics for required (white) and elective (shaded) courses identified in Table 1.	Axial Loading	Centroids & Mom. of Inertia	Equilibrium	Friction	General (**F**, **M**, reactions)	Shear & Moment Diagram	Trusses & Frames
CE 222 Strength of Materials	X	X	X	X	X	X	X
CE 330 Structural Theory		X	X		X	X	X
CE 331 Structural Theory II						X	X
CE 340 Fluid Mechanics				X	X		
CE 432 Structural Design in Concrete						X	
CE 433 Structural Design in Steel						X	X
CE 437 Timber Design					X	X	X
CE 439 Computer-Aided Structural Design					X		
Total in required courses	**1**	**2**	**2**	**1**	**3**	**4**	**3**
Total in elective courses	**0**	**0**	**0**	**0**	**2**	**2**	**2**

Table 8. Summary of Performance Criteria for Outcomes Assessment Vehicles

Assessment Vehicle	**Performance Criteria**
Fundamentals of Engineering Exam	1. Exceed overall national pass rate 2. Minimum 80% pass rate for each year 3. Exceed national percent correct score for individual topics
Prerequisite Inventory	1. Percent correct will exceed national percent correct score on FE by topic 2. Percent correct on each topic will improve throughout curriculum

performance criteria, and discuss the implementation of recent curriculum modifications that were identified using PI data.

Student performance on the FE in mathematics is presented in Figure 1, where percent correct scores for OUCE, the State of Ohio, and the national average since 1992 is plotted. It is clear that there is a general but consistent downward trend for all data sets. To assess OUCE with respect to FE performance criteria 3 (as defined in Table 8), the departure is calculated as the difference between the national average percent correct score and the OUCE percent correct score. While there is some variability in the departure, OUCE student performance has generally declined over the past ten years when compared to the national average as seen in Figure 2.

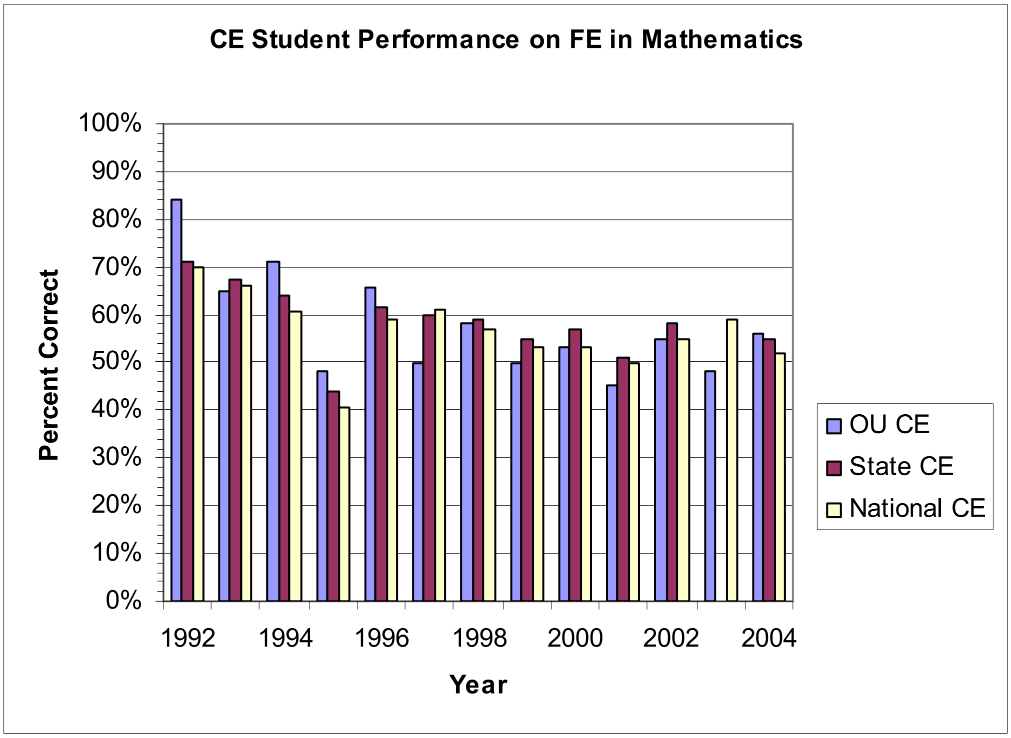

Figure 1. FE Mathematics % Correct Scores

While it may seem reasonable that an initial response would be to question the quality of the calculus sequence in the mathematics department, it still falls to the individual engineering department to address identified student weaknesses. To further investigate the declining mathematics performance, results from the PI mathematics questions were evaluated by subtopic and by class standing for AY 00-01 and AY 01-02. For basic math skills such as algebra, line and exponential equations, etc., student averages were near 70% in the sophomore level PIs, increasing to 80-90% for the junior and senior level PIs. However, while sophomore level PIs indicated that students could obtain an average of 63% correct in integration or 75% correct in trigonometry, those scores dropped to 42% for both subtopics in the junior and senior level PIs.

The conclusion drawn from this data was that OUCE students were given fundamental math skills in the freshman and sophomore calculus sequence, but they were quickly diminished as subsequent courses did not sufficiently reinforce these skills. In response to this observation, an additional course was developed in cooperation with the mathematics department for the late sophomore or junior year entitled "Numerical Methods for Civil Engineers" in which problem solving focuses on CE related topics and MATLAB is employed as the computational tool.

Student performance on the mathematics questions for all PIs by year and by course standing is presented in Table 9. While overall performance was statistically the same for all course standings and the FE for AY 00-01, a pattern of diminished performance at the junior level followed by recovery in the senior year is seen for the three most recent AYs. Percent correct on all PI questions administered from 2000-2004 was 57% compared to 51% for OUCE students

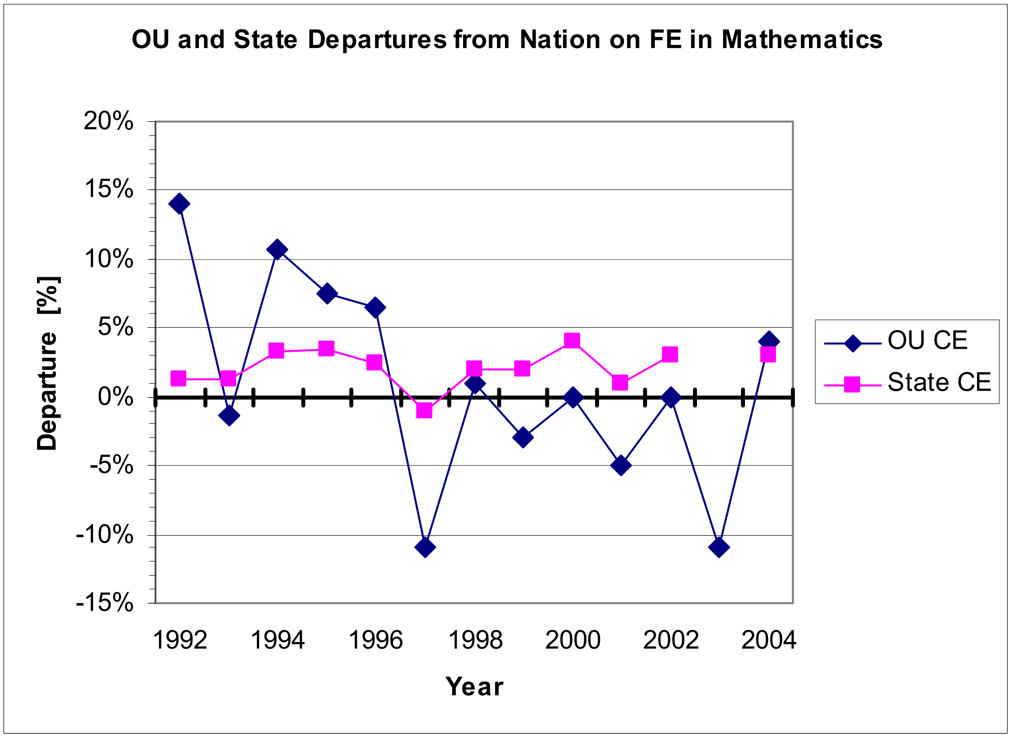

Figure 2. FE % Correct in Mathematics Compared to the Nation

and 54% for the national average percent correct score on the mathematics portion of the FE over the same time period. Further, while the PI results in the senior year still over-predict FE performance by approximately 10%, the class of 03-04 was the first in 8 years to exceed the state average on the FE and the first in 6 years to exceed the national average on the FE. This class was the first to complete the required curriculum that was revised in 2001, which included the newly developed numerical methods course. For the mathematics PI questions, the level of difficulty is being reviewed to better predict student performance and prepare students for the types of questions they might encounter when taking the FE Exam.

Table 9. PI Results for Mathematics by Academic Year and Course Standing

AY	200 level	300 level	400 level	FE OU	FE Nat.
2000-2001	48	55	51	45	50
2001-2002	64	44	60	55	55
2002-2003	62	54	67	48	59
2003-2004	61	51	64	56	52
2000-2004	59	50	61	51	54

Another trend was observed when reviewing the PI data for statics. As the basis for many subsequent courses that continue to develop engineering concepts upon the foundations set in the statics course, it would be expected that statics skills would continue to get stronger as a student progressed through the curriculum. Results from the statics questions on all PIs for all course levels and the FE results are presented in Table 10. Since the 2003 FE Exam was the only time in the past 7 years that the national average was not exceeded, the statics PI questions were not needed to help identify a weakness. However, while the performance criteria for PIs to improve throughout the curriculum was met in all cases except one, the average for the seniors over-predicts their performance on the FE by an average of more than 20%. As with the mathematics questions, the level of difficulty of the statics PI questions is being reviewed to better predict student performance and prepare students for the types of questions they might encounter when taking the FE Exam.

Table 10. PI Results for Statics by Academic Year and Course Standing

AY	200 level	300 level	400 level	FE OU	FE Nat.
2000-2001	46	58	79	49	46
2001-2002	35	71	80	73	62
2002-2003	-	75	73	49	55
2003-2004	32	69	87	61	51
2000-2004	38	68	80	58	54

Results from the PIs on the physics and geology questions were compared to a performance criterion of 60%, which is approximately the average percent correct score on all FE topics over the past four years. Physics questions are only asked on the statics PI, and geology questions are only asked on the geotechnical engineering PI. Student performance in these areas is presented by year in Table 11. Consistent with the results from the statics PIs, student performance in physics demonstrated substantial improvement from the first year of administering the PI and has surpassed the 60% benchmark in each of the last three years. While the 60% benchmark was only realized in AY 03-04 on the geology PI questions, performance has improved consistently over the past 4 years. Improvement in the performance on the geology questions has been attributed to better communication and interaction with the faculty in Geological Sciences who teach the introductory geology course for the civil engineering students.

Table 11. PI Results for Physics and Geology by Academic Year

AY	Physics	Geology
2000-2001	57	41
2001-2002	79	51
2002-2003	72	54
2003-2004	71	63
2000-2004	70	52

There are also many examples where the results from the PI have been shown to be relatively good predictors of student performance on the FE Exam. Student PI performance for strength of materials (called mechanics of materials on the FE Exam) is presented by year and course standing in Table 12. In nearly all cases, performance has improved as students progressed through the curriculum. More notably, with the exception of AY 00-01, performance on the PI in the senior year has been a good predictor of student performance on the FE Exam.

Table 12. PI Results for Select Topics by Academic Year and Course Standing

AY	300 level	400 level	FE OU	FE Nat.
2000-2001	37	48	67	60
2001-2002	40	51	57	54
2002-2003	53	50	51	54
2003-2004	52	59	58	54
2000-2004	47	53	58	56

The prerequisite inventory continues to be modified and tested. Coverage matrices by course and by sub-topic have been reviewed and re-distributed, testing methods (e.g. short answer vs. multiple choice questions) have been used, individual questions have been modified, questions have been re-used at multiple levels, consideration was given to allowing students to use the FE Supplied Reference Handbook, and results have been subject to several data interpretation methods. The goal of the PI is to offer the ability to predict FE performance in the quarters and years leading to a student taking the FE, such that course and curriculum weaknesses can be identified quickly and addressed before subsequent students take the course.

The FE can be a useful tool in the process of outcomes based assessment, but has its limitations as identified previously. The PI can address some of those deficiencies by providing a more timely mechanism for closing the loop and addressing small curricular weaknesses. The process of developing any assessment vehicle and making it an effective tool is a continuous one. Future considerations for the PI include the evaluation of an on-line system for greater flexibility, planning, and data management. Further, while the PI is a valuable tool for assessing math, science, and engineering related outcomes, the PI cannot be used to assess all program outcomes. Specifically, outcomes that assess Criterion 3 skills such as communication, teamwork, etc., often require the use of assessment vehicles that are more subjective. In as much, the FE and PI are only two of 9 vehicles used by OUCE faculty in the assessment of specific program outcomes. For example, additional assessment vehicles used by OUCE faculty in conjunction with the FE and PI results include a confidential peer evaluation to assess team performance, oral team presentation evaluations, assessment of overall report quality, co-op and institutional research surveys, and senior exit surveys.