Evaluating Engineering Problem Solving Skills of First-Year Engineering Students

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Abstract

Students in our Introduction to Engineering course sequence at the University of Arkansas often tell us, "we know all of this already." Therefore, in the Fall Semester of 2009, we administered a pre-test during the first week of Introduction to Engineering I covering the engineering problem solving topics to be covered during the semester. These topics included engineering problem solving fundamentals, statics, statistics, and engineering economics. The results show that students did not "know this all ready" but did learn it sufficiently.

Introduction

The Freshman Engineering Program (FEP) is the first-year experience program for College of Engineering (CoE) students at the University of Arkansas (UofA). The objective of the FEP is to support the achievement of the retention and graduation rate goals established by the CoE, with particular emphasis on the retention of new freshmen to their sophomore year. The FEP is executed via two sub-programs: the Freshman Engineering Academic Program (FEAP) and the Freshman Engineering Student Services Program (FESSP). These sub-programs are executed by a faculty director, two full-time professional staff members, two instructors, and six graduate teaching assistants.

A key element of both the FEAP and the FESSP is the Introduction to Engineering course sequence: a sequence of two, one-credit courses taught during the Fall and Spring semesters. The sequence provides students with a broad overview of topics intended to assist them as they transition from high school seniors to first-year engineering students and ultimately to their chosen engineering major. These topics include Engineering Problem Solving, the Engineering Design Process, Computer Skills, the Major Section Process, and Professional Development [1]. In this paper, we evaluate gains in student knowledge related to the Engineering Problem Solving portion of the first semester of the course sequence.

Engineering Problem Solving

Engineers are problem solvers. Therefore, we employ a variety of engineering topics to train students in applying a disciplined approach to solving problems. The topics used to facilitate the engineering problem solving approach in the first semester include Engineering Problem Solving Fundamentals, Statics, Statistics, and Engineering Economy.

Engineering Problem Solving Fundamentals

Students review concepts such as unit conversions, scientific notation, significant figures, order of operations, and dimensional analysis.

Statics

Students are introduced to the topic of mechanics and specifically to the sub-topic of rigid-body mechanics. Students receive instruction on vector addition, basic trigonometric functions, and the creation of simple free-body diagrams.

Statistics

Students are introduced to the concepts associated with random variables and descriptive statistics. They are also introduced to basic spreadsheet applications.

Engineering Economics

Students are introduced to the concepts associated with the time value of money, cash flow diagrams, loan payments, and evaluating equipment alternatives using net present cost.

Pre-Test

While the overall teaching evaluations associated with the Introduction to Engineering course sequence have been positive, one of the complaints we often hear from students is "we already know all of this." In an attempt to assess the validity of this complaint and the effectiveness of the course, we decided to administer a pre-test over the material that would be covered during the first semester of the course sequence.

On Thursday, September 3, 2009, students in Introduction to Engineering I completed the initial assessment of their engineering problem solving skills by completing the "Exam 1 and 2 Pre-Test" (i.e., the pre-test) The assessment was executed during the second week of class to allow the students a chance to become comfortable with the collegiate atmosphere before being exposed to the problem solving topics covered by the pre-test. Each student was given an exam which contained twelve problems, and each student was randomly assigned five problems to attempt. Students were allowed 50 minutes to complete their assigned problems. They were encouraged to put forward their best effort on each problem, but they were told that "I have no idea" was an acceptable answer.

Students were informed that the grade for the pre-test would be based solely on the completion of the five problems. In order to maintain grading equality across the six sections of Introduction to Engineering I, the six teaching assistants for the course were each assigned two problems to grade. The teaching assistants were instructed to keep rubrics for partial credit awarded. (Note that the same teaching assistants grades the corresponding problems on Exams 1 and 2).The graded problems were then reorganized by student and entered into a database. The average scores for the pre-test may be found in Table 1. The headings of on the table provide the

following information: the topic, the problem number, a description of the problem, the number of points possible, the average number of points earned on the problem and the corresponding percentage, and the number of students attempting the problem.

Table 1. Exam 1 and 2 Pre-Test Results

Topic	Problem	Description	Points	Average	Percent	Students
Engineering Problem Solving Fundamentals	1	Significant Figures/ Scientific Notation	8	5.5	69%	129
	2	Unit Conversions	21	12.8	61%	135
	3	Order of Operations/ Scientific Notation	15	6.3	42%	123
	4	Dimensional Analysis	25	4.3	17%	152
Statics	5	Free-Body Diagram/ Vector Addition	35	4.3	12%	145
Statistics	6	Descriptive Statistics	15	5.4	36%	152
	7	Excel Cell References	15	1.9	12%	141
	8	Reading Graphs	25	18.3	73%	150
	9	Excel Formulae	20	8.8	44%	150
Engineering Economics	10	Future Worth	15	3.2	21%	140
	11	Annual Worth	25	1.0	4%	132
	12	Loan Repayment Schedule	35	2.4	7%	130
		Total*	254	74.2	29%	

*Total is the sum of the problem averages, not weighted by number of students.

On only three of the twelve problems (1, 2, and 8) were students able to average enough points for a passing grade (60%) and the overall average falls well short of passing at 29%. The numbers from the pre-test indicate that there is a significant knowledge gap in what these first-year students enter the program with and what they are expected to know at the end of the first semester.

Post-Test

During Introduction to Engineering I, two, in-class, closed-notes exams are administered (i.e., the post-test). Exam 1 contains problems related to Engineering Problem Solving Fundamentals and Statics (corresponding to pre-test problems 1-6), and Exam 2 contains problems from Statistics and Engineering Economics (pre-test problems 7-12). The exam problems are the exact problems as written on the pre-test, but students are not alerted that they would be exact replicas. As with the pre-test, students are given 50 minutes to complete each exam, but during the actual exams, students are expected to work all the problems. To maintain consistency, each problem is graded by the same teaching assistant (using the same rubric) who graded that problem on the pre-test. The scores for individual problems were recorded to allow comparison to the pre-test. The scores for the post-test are summarized in Table 2.

Table 2. Post-Test Results

Topic	Problem	Description	Points	Average	Percent	Students
Engineering Problem Solving Fundamentals	1	Significant Figures/ Scientific Notation	8	7.1	89%	389
	2	Unit Conversions	21	17.4	83%	389
	3	Order of Operations/ Scientific Notation	15	9.1	61%	389
	4	Dimensional Analysis	25	17.4	70%	389
Statics	5	Free-Body Diagram/ Vector Addition	35	23.4	67%	389
Descriptive Statistics	6	Descriptive Statistics	15	11.5	77%	371
	7	Excel Cell References	15	11.9	80%	371
	8	Reading Graphs	25	21.3	85%	371
	9	Excel Formulae	20	18.7	94%	371
Engineering Economics	10	Future Worth	15	13.1	88%	371
	11	Annual Worth	25	21.1	84%	371
	12	Loan Repayment Schedule	35	26.7	76%	371
		Total*	254	198.8	78%	

*Total is the sum of the problem averages, not weighted by number of students.

Conclusions

After being exposed to the topics in Introduction to Engineering I, the overall average for the twelve problems rose from 29.2% on the pre-test to an acceptable 78.3% on the post-test. Performance comparisons for each individual problem are shown in Table 3.

Table 3. Comparison of Pre-Test and Post-Test Performance

Topic	Problem	Description	Pre-Test Average	Post-Test Average	Difference
Engineering Problem Solving Fundamentals	1	Significant Figures/ Scientific Notation	68.8%	88.8%	20.0%
	2	Unit Conversions	61.1%	83.0%	21.9%
	3	Order of Operations/ Scientific Notation	42.2%	61.0%	18.8%
	4	Dimensional Analysis	17.2%	69.5%	52.3%
Statics	5	Free-Body Diagram/ Vector Addition	12.4%	66.9%	54.5%
Descriptive Statistics	6	Descriptive Statistics	36.2%	76.7%	40.5%
	7	Excel Cell References	12.4%	79.6%	67.2%
	8	Reading Graphs	73.2%	85.1%	11.9%
	9	Excel Formulae	43.8%	93.7%	49.8%
Engineering Economics	10	Future Worth	21.2%	87.5%	66.3%
	11	Annual Worth	3.8%	84.4%	80.5%
	12	Loan Repayment Schedule	6.9%	76.2%	69.3%
		Total*	29.2%	78.3%	49.1%

*Total is weighted by points possible, but not number of students attempting each problem.

Prior Knowledge, Improved

The class averages for problems 1, 2, and 8 were above the passing level (60%) on the pre-test. Our students likely have a basic understanding of these concepts (Significant Figures, Unit Conversions, and Reading Graphs) from their high school math and science courses. However, the combined average for these three problems did rise from 67.8% on the pre-test to 84.8% on the post-test. Students are exposed to some of this material within the chemistry class taken by most first-year engineering students making it somewhat unclear how much covering these topics in our course benefits the students.

Initially Ignorant, Taught

The pre-test also indicates that there are several problems (7, 10, 11, and 12) that our students either did not understand or had no idea how to work upon entering Introduction to Engineering I, but were able to learn how to solve reasonably well. The pre-test combined average for these problems was only 9.4%, but after being exposed to the material (Microsoft Excel Cell References and Engineering Economics in class, the students scored an average of 80.9% on these four problems on the post-test. The largest pre-test to post-test improvement was on problem 11 which involved calculating the monthly savings required to reach a desired future amount and drawing the corresponding cash flow diagram. Students went from not knowing what a cash flow diagram was to being able to construct one sufficiently. For these problems, we are not aware that they are getting the knowledge anywhere else, so our teaching efforts seem to be successful.

Initially Ignorant, Somewhat Taught

Like the previous group, problems 4 and 5 were not answered well on the pre-test (combined average of 14.4%). The post-test average rose to 68.0%; however, this level of performance is still below our expectations. The topics covered by these problems (Dimensional Analysis and Statics) are important for first-year engineering students, so we are examining our teaching strategies for these concepts.

Somewhat Known, Somewhat Taught

Students exhibited a similar amount of pre-test knowledge (combined average of 41.1%) on the remaining three problems (3, 6, and 9). However, the post-test result tells a different story for each problem. Problem 3 (Order of Operations) had the worst post-test average (61.0%) among the twelve problems. Perhaps, we did not spend enough time focusing on this topic, as our students should be scoring well on this problem. Problem 6 (Descriptive Statistics) had a post-test average of 76.7%. Overall, students grasped the basic concepts for this material but often made a mistake such as confusing mean with median or incorrectly calculating standard deviation. Problem 9 (Excel formulae) shows drastic improvement to an average of 93.7% on the post-test. The scores on the pre-test were polarized (students either scored well on the problem or had not been previously exposed to the material). After everyone had been exposed to the material, they all scored similarly well.

Honors Students

Those students who take Honors Introduction to Engineering I are those that achieved much in high school and often were exposed to advanced or extra material. Therefore, we see some differences in their pre-test scores, but generally the same trends for improvement. The pre-test average for honors students was 39.7% and increased to 86.5% for the post-test. As expected, the individual problem averages (as seen in Table 4) are each about 10% higher than the class in general.

Table 4. Comparison of Pre-Test and Post-Test Performance for Honors Introduction to Engineering I Students Only

Topic	Problem	Description	Pre-Test Average	Post-Test Average	Difference
Engineering Problem Solving Fundamentals	1	Significant Figures/ Scientific Notation	83.3%	93.4%	10.0%
	2	Unit Conversions	78.5%	89.3%	10.8%
	3	Order of Operations/ Scientific Notation	52.6%	71.8%	19.2%
	4	Dimensional Analysis	26.2%	78.3%	52.1%
Statics	5	Free-Body Diagram/ Vector Addition	22.6%	79.8%	57.2%
Descriptive Statistics	6	Descriptive Statistics	46.0%	84.7%	38.7%
	7	Excel Cell References	16.9%	88.8%	71.9%
	8	Reading Graphs	82.9%	85.8%	2.9%
	9	Excel Formulae	71.1%	96.8%	25.8%
Engineering Economics	10	Future Worth	39.0%	93.4%	54.4%
	11	Annual Worth	6.8%	94.6%	87.9%
	12	Loan Repayment Schedule	9.6%	87.6%	78.0%
		Total*	39.7%	86.5%	46.8%

*Total is weighted by points possible but not number of students attempting each problem.

Future Work

Comparing the results from the exams to the pre-test gives us some insight to what our students are learning. The real goal would be that they retain that knowledge. In order to assess that, we would need to give another test on the material after the students have had some time away from the material. Thus, we should give another post-test at the beginning of the next semester to our students in Introduction to Engineering II.

Also, we recognize that we have only examined the learning over the Introduction to Engineering I course. A similar pre-test/exams/post-test system should be implemented in the Introduction to Engineering II course in which we cover topics such as mass balances, algorithm development, and computer programming.

Bibliography

1. Schneider, K., H. Schluterman, and C.R. Cassady (2009). "A First-Year Experience Course for Engineering Students at the University of Arkansas," *Proceedings of the 2009 Midwest Section Conference of the American Society for Engineering Education*.

Biographies

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