Evaluating Retention of Engineering Problem Solving Skills of First-Year Engineering Students

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Abstract

One of the overriding topics in education is determining how well students retain knowledge from a particular course. In this study, we wished to evaluate not only the improvement of problem solving skills during the Fall semester but also the retention of those skills to the beginning of the Spring semester. Therefore, in the Fall Semester of 2010, we administered a Pre-Test during the first week of the Introduction to Engineering I course. The Pre-Test content included the engineering problem solving topics to be covered during the upcoming semester. During the Fall semester, we administered two, in-class, closed-notes, closed-book exams. In addition to the Pre-Test and the exams in the Fall, students were unexpectedly presented a Post-Test on the Introduction to Engineering I material during the first week of their Introduction to Engineering II course in the Spring 2011. Student performance improved remarkably between the Pre-Test and the in-class exams. Although student performance dropped slightly from the in-class exams to the Post-Test, many key concepts and skills were retained.

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, metric prefixes, significant figures, order of operations, and dimensional analysis.

Electric Circuits

Students are introduced to the topic of electric circuits. Students receive instruction on total resistance, Ohm’s law, power dissipation, and the creation of simple circuit 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 heard from students was “we already know all of this.” In an attempt to assess the validity of this complaint and the effectiveness of the course, we administered a Pre-Test over the material to be covered during the first semester of the course sequence.

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 first week of class (Wednesday, August 25 and Thursday, August 26, 2010) before students were exposed to any of the problem solving topics covered by the Pre-Test. Each student was given an exam which contained thirteen 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 ten sections of Introduction to Engineering I, the six teaching assistants for the course were each assigned a problem to grade and the two instructors divided remaining problems. The graders kept rubrics for partial credit awarded. (Note that the same teaching assistants and instructors graded the corresponding problems on Exams 1 and 2 as well as the Post-Test). The graded problems were then reorganized by student and entered into a database. A description of the topics associated with each problem along with the number of points possible is located in Table 1. The headings of the table provide the following information: the topic, the problem number, a description of the problem, the number of points possible.

Table 1. Test Problems

Topic	Problem	Description	Possible
Engineering Problem Solving Fundamentals	1	Significant Figures/ Scientific Notation/ Metric Prefixes	12
	2	Unit Conversions	12
	3	Order of Operations/ Scientific Notation	12
	4	Dimensional Analysis	15
Electric Circuits	5	Total Resistance/ Ohm's Law	20
Statistics	6	Descriptive Statistics	12
	7	Excel Cell References	12
	8	Reading Graphs	14
	9	Excel Formulae	12
Engineering Economics	10	Future Worth	15
	11	Annual Worth	15
	12	Loan Repayment Schedule	20
Homework Policy	13	Homework Policy	20
		Total Points Possible	191

A total of 586 students participated in the Pre-Test. The average scores for the Pre-Test may be found in Table 2. Note that we included a break-down between the students in the Regular and Honors sections. The headings of the table include the number of students that worked each problem, the average number of points earned by the students that worked the problem, and the percentage. We assume that our Honors students are generally exposed to more of the Engineering Problem Solving topics during their high school careers and therefore will perform better than the Regular students on the Pre-Test. To test this hypothesis, we constructed a 95% confidence interval on the difference of the means between the Regular and Honors sections for each problem in the Pre-Test. The null hypothesis is that the difference in the means is zero, and the alternative hypothesis is that the mean of the Honors sections is greater than that of the regular sections. We were able to reject the null hypothesis and conclude the Honors students performed better on all problems except problems 3, 7, 11, and 12.

Table 2. Pre-Test Results

	Regular Sections			Honors Sections			All Sections		
Problem	Students	Average	Percent	Students	Average	Percent	Students	Average	Percent
1	170	2.6	22%	51	4.5	38%	221	3.1	26%
2	176	3.9	32%	51	6.0	50%	227	4.4	36%
3	157	7.3	61%	69	7.6	64%	226	7.4	62%
4	164	3.2	21%	59	5.6	37%	223	3.8	25%
5	146	1.8	9%	56	4.5	23%	202	2.5	13%
6	159	6.5	54%	55	8.2	69%	214	6.9	58%
7	150	1.4	12%	69	1.8	15%	219	1.6	13%
8	150	8.9	63%	56	11.1	79%	206	9.5	68%
9	166	5.7	48%	49	8.8	73%	215	6.4	54%
10	175	4.9	33%	55	7.3	49%	230	5.5	37%
11	166	2.3	15%	59	2.6	18%	225	2.4	16%
12	161	0.95	5%	54	1.3	7%	215	1.0	5%
13	156	2.8	14%	60	4.0	20%	216	3.1	16%
Overall*		52.3	27%		71.3	38%		57.6	30%

*Overall average represents the sum of problem averages. Overall percent is total average divided by total points possible (191)

Exams

During the Introduction to Engineering I course, two, in-class, closed-notes exams were administered (i.e., the exams). A total of 549 students completed the first exam (397 from the Regular sections and 152 from the Honors sections), and 525 students completed the second exam (374 students from the Regular sections and 151 from the Honors sections). Exam 1 contained problems related to Engineering Problem Solving Fundamentals, Electric Circuits, and the Homework Policy (corresponding to Pre-Test problems 1-6 and 13), and Exam 2 contained problems from Statistics and Engineering Economics (Pre-Test problems 7-12). The exam problems were replicas (same problems with different values) of the Pre-Test problems, but students were not alerted that they would be the same. As with the Pre-Test, students were given 50 minutes to complete each exam, but during the actual exams, students were expected to work all the problems. To maintain consistency, each problem was graded by the same teaching assistant or instructor (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 two, in-class, closed-notes exams are summarized in Table 3.

Post-Test

On Monday, January 24 and Tuesday, January 25, 2011, students in the Introduction to Engineering II course completed a Post-Test on the material covered in Introduction to Engineering I. The Post-Test was administered the same way as the Pre-Test was in the Fall. Each student was given an exam which contained the thirteen 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. Their results are summarized in Table 4.

Table 3. Exam Results

	Regular Sections		Honors Sections		All Sections	
Problem	Average	Percent	Average	Percent	Average	Percent
1	7.9	66%	8.4	70%	8.0	67%
2	8.7	72%	10.0	83%	9.0	75%
3	9.0	75%	9.2	77%	9.0	75%
4	7.8	52%	11.7	78%	8.9	59%
5	15.0	75%	17.6	88%	15.7	78%
6	8.6	71%	9.6	80%	8.9	74%
7	8.2	68%	9.7	81%	8.7	72%
8	12.7	91%	13.9	99%	13.0	93%
9	10.4	87%	11.5	96%	10.8	90%
10	13.3	89%	13.6	91%	13.4	89%
11	11.0	73%	13.1	87%	11.6	77%
12	14.5	72%	18.1	90%	15.5	78%
13	16.7	84%	17.9	90%	17.0	85%
Overall	143.7	75%	164.3	86%	149.5	78%

Table 4. Post-Test Results

	Regular Sections			Honors Sections			All Sections		
Problem	Students	Average	Percent	Students	Average	Percent	Students	Average	Percent
1	126	6.8	56%	49	7.7	64%	175	7.0	58%
2	103	6.6	55%	54	8.3	69%	157	7.1	60%
3	130	8.6	71%	57	9.1	76%	187	8.7	73%
4	114	6.6	44%	44	10.3	69%	158	7.6	51%
5	107	11.3	57%	49	17	85%	156	13.1	65%
6	123	7.5	63%	59	8.5	71%	182	7.8	65%
7	123	9.3	77%	51	11.4	95%	174	9.9	82%
8	117	12.1	86%	51	12.2	87%	168	12.1	87%
9	100	8.4	70%	49	9.6	80%	149	8.8	73%
10	116	12.0	80%	68	13.2	88%	184	12.4	83%
11	117	8.3	55%	33	11.1	74%	150	8.9	59%
12	120	8.6	43%	44	12.9	65%	164	9.8	49%
13	130	15.7	78%	57	17.0	85%	187	16.1	80%
Overall*		122	64%		148.3	78%		129.5	68%

*Overall average represents the sum of problem averages. Overall percent is overall average divided by total points possible (191)

Results and Discussion

After being exposed to the topics in Introduction to Engineering I, the overall average for the thirteen problems rose from 30.2% on the Pre-Test to an acceptable 78.3% on the exams. After being given time to forget over the winter break, the overall average dips to 67.8% but is still significantly higher than that of the Pre-Test. Performance comparisons for each individual problem are shown in Table 5.

Table 5. Comparison of Pre-Test, Exam, and Post-Test Performance

	Regular Sections			Honors Sections			All Sections		
Problem	Pre-Test	Exams	Post-Test	Pre-Test	Exams	Post-Test	Pre-Test	Exams	Post-Test
1	22%	66%	56%	38%	70%	64%	26%	67%	58%
2	33%	73%	55%	50%	83%	69%	36%	75%	60%
3	61%	75%	71%	64%	77%	76%	62%	75%	73%
4	21%	52%	44%	37%	78%	69%	25%	59%	51%
5	9%	75%	57%	23%	88%	85%	13%	78%	65%
6	54%	71%	63%	69%	80%	71%	58%	74%	65%
7	12%	68%	77%	15%	81%	95%	13%	72%	82%
8	63%	91%	86%	79%	99%	87%	68%	93%	87%
9	48%	87%	70%	73%	96%	80%	54%	90%	73%
10	33%	89%	80%	49%	91%	88%	37%	89%	83%
11	15%	73%	55%	18%	87%	74%	16%	77%	59%
12	5%	72%	43%	7%	90%	65%	5%	78%	49%
13	14%	84%	78%	20%	90%	85%	16%	85%	80%
Overall	27%	75%	64%	38%	86%	78%	30%	78%	68%

Individual Problem Distribution

Although there are differences in the averages for Honors and Regular students for many problems, the averages for individual problems seem to follow the same patterns. Problems may be categorized based on students' initial knowledge on the Pre-Test, their ability to answer the question on the exam, and how well they retained the knowledge on the Post-Test.

Initially Ignorant, Learned

From a teaching standpoint, this is the ideal category. These include problems in which the students performed poorly on the Pre-Test, showed increased knowledge on the exam, and continued to answer successfully on the Post-Test. The problems which best reflect this model are 7, 10, and 13. These questions cover the topics of Excel References, Future Worth, and the FEP Homework policy. Problem 7 required the students to understand Microsoft Excel cell references. Again, most of our students had little knowledge of Excel initially, and many mistook the multi-part question as a multiple-choice. The unique result is that scores were actually higher on the Post-Test than the exam. This could be due to the fact that Microsoft Excel continued to be used in the Introduction to Engineering I course after the second exam. Problem 10 concerned determining a future value of a present sum of money. Students were able to easily learn how to apply this simple formula. Anecdotal evidence indicates many of the points that were missed on problem 10 on the Post-Test concerned the cash flow diagram that was required. The FEP Homework policy (problem 13) is certainly expected in this category. There is no reason the student should have prior knowledge of our particular policy, but we would expect by using it throughout the semester they should be familiar with it. The only concern here is that we would expect students to be perfect on this information.

Initially Ignorant, Somewhat Learned

This category would contain problems in which students did not do well on the Pre-Test, performed well on the exam, but may have not have performed quite as well on the Post-Test. Some questions that fit this category include 1, 2, 4, 5, and 11. The majority of these problems were on Exam 1. Thus, their lower scores on the Post-Test may be more a function of a longer time between direct questioning on these matters. The assumption was that concepts of significant figures, scientific notation, metric prefixes (problem 1), unit conversions (problem 2), and dimensional analysis (problem 4) would arise naturally in problems throughout the semester. However, these results emphasize the need to repeat concepts throughout the semester. Problem 5 dealt with Electric Circuits. While students did not perform at a passing rate on the Post-Test, their scores are still much better than the Pre-Test. The real goal of the Electric Circuits unit is to teach students how to present handwritten work in a professional manner. Therefore, the lower scores on this question are outweighed by the success on question 13. It is also encouraging that the Honors students did perform well on the Circuits question. The final question in this category is problem 11 which dealt with the future value of a periodic payment. Again, the Post-Test scores are much better than the Pre-Test scores, but not at a passing level. The anecdotal evidence on this problem indicates two issues. The first is like problem 10 where students failed to construct a proper cash flow diagram. The second is students chose the wrong economic equation. This again indicates a lack of familiarity with the terms and variables used. This could be remedied by supplemental quizzes over past terminology.

Initially Ignorant, Not Learned

As teachers, this is the most disappointing category. This would include questions where the students performed poorly on the Pre-Test and Post-Test. Fortunately, problem 12, Loan Repayment, is the only placed in this category. Students score on the Pre-Test indicates most had no idea how to answer the question. There was an amazing increase of scores on the exam, but a significant reduction on the Post-Test. The Post-Test was much better than the Pre-Test, but below our standards. Many students were able to calculate the loan repayment amount, but could not reconstruct a loan table to show how much of each payment was interest. There is also some speculation that since the students knew the grades for the Post-Test would not be dependent on their scores they chose to not attempt the table portion.

Somewhat Known, Somewhat Learned

When planning the curriculum, this category needs to be reconsidered. These are problems which the students did somewhat well on the Pre-Test and only moderately better on the Post-Test. This indicates less time could be devoted to these concepts, or more time needs to be devoted to these to get to a mastery level. This category includes problems 3, 6, 8, and 9. Problem 3 involved order of operations and scientific notation. This is a skill which should be mastered by our students, but the assumption is students will learn it through applications throughout the semester and in their various other classes. That does not seem to be the case. Problems 6, 8, and 9 deal with topics used to explore Microsoft Excel. Problem 6 includes descriptive statistics. The anecdotal evidence on this problem is that students primarily missed the calculation of standard deviation on both the Pre-Test and Post-Test. Students, however, do understand the Microsoft Excel formula to use. Problem 8 concerned reading graphs. It was the highest scoring question at all three testing times. This means that we need very little instruction for this topic. The key instruction during this time is actually on how to construct graphs in Microsoft Excel. Problem 9, the last in this category, dealt with Microsoft Excel Formulae. This problem had the second highest score on the exam stage which means students did become familiar with them. However, the large drop to the Post-Test again testifies to the need for supplemental reinforcement.

Comparisons to 2009 Data

Beyond assessing our students' ability to learn engineering problem solving skills, we also need to examine these results as an assessment of our ability to teach these skills and help us determine areas of focus. For this we want to consider the Pre-Test/Exam results from the previous year (2009). Table 6 summarizes the results from our previous paper[2].

Table 6. Comparison of 2009 Pre-Test and Exam Performance

Topic	Problem	Description	Possible	Pre-Test Percent	Exam Percent
Engineering Problem Solving Fundamentals	1	Significant Figures/ Scientific Notation	8	68.8%	88.8%
	2	Unit Conversions	21	61.1%	83.0%
	3	Order of Operations/ Scientific Notation	15	42.2%	61.0%
	4	Dimensional Analysis	25	17.2%	69.5%
Statics	5	Free-Body Diagram/ Vector Addition	35	12.4%	66.9%
Descriptive Statistics	6	Descriptive Statistics	15	36.2%	76.7%
	7	Excel Cell References	15	12.4%	79.6%
	8	Reading Graphs	25	73.2%	85.1%
	9	Excel Formulae	20	43.8%	93.7%
Engineering Economics	10	Future Worth	15	21.2%	87.5%
	11	Annual Worth	25	3.8%	84.4%
	12	Loan Repayment Schedule	35	6.9%	76.2%
		Total*	254	29.2%	78.3%

*Total Percent is the sum of the average points scored on each problem divided by the total possible (254).

Changes for 2010

From these results we learned several things which led to changes in the Introduction to Engineering I curriculum and presentations. Within the Engineering Problem Solving Fundamentals, we found that students had a decent grasp of scientific notation when they began the class and could perform unit conversions, so we naturally extended the element of using metric prefixes to express very large or very small quantities.

The Statics unit had one of the poorest performances among our students in the 2009 group. We believe this had more to do with the students' inability to use trigonometric relationships rather than a deficiency to understand how to reason through these problems. Thus, the Statics unit was replaced by Electric Circuits unit. This eliminated the need for students to learn trigonometry within the Introduction to Engineering I course and instead made the problems only a matter of engineering reasoning and algebraic manipulation.

The third major change to the Pre-Test for 2010 was the addition of a problem relating to our homework policy. One of our focuses as a first-year engineering course is to teach our student to present work in a professional manner. To facilitate this, we have developed an explicit homework policy for the students. To further enforce this concept, a question was added to the exam.

Beyond the content changes from year to year, there are also several administrative changes which can lead to slight variances in results. One of the toughest is keeping the grading rubric consistent. Within a given year, we tried to keep grading on the Pre-Test, Exams, and Post-Tests consistent by having the same teaching assistant or instructor grade the same problem for each student. Across years however, the teaching assistants obviously change. Also, there are changes to the points possible leading to necessary changes to the rubrics. Some of these changes are evident by comparing the Pre-Test results in Table 7. We see that individual questions show significant differences in the Pre-Test averages.

Although individual questions show big differences from year to year, the overall average is virtually the same at 29.2% in 2009 and 30.2% in 2010. We are also encouraged that the replacement of Circuits for Statics shows similar Pre-Test results so we have a baseline for comparison.

Table 7. Pre-Test Results 2009 and 2010

			2009		2010	
Topic	Problem	Description	Possible	Average	Possible	Percent
Engineering Problem Solving Fundamentals	1	Significant Figures/ Scientific Notation/ Metric Prefixes**	8	68.8%	12	25.6%
	2	Unit Conversions	21	61.1%	12	36.3%
	3	Order of Operations/ Scientific Notation	15	42.2%	12	61.6%
	4	Dimensional Analysis	25	17.2%	15	25.3%
Statics/ Electric Circuits	5	** complete content change	35	12.4%	20	12.7%
Statistics	6	Descriptive Statistics	15	36.2%	12	57.7%
	7	Excel Cell References	15	12.4%	12	13.0%
	8	Reading Graphs	25	73.2%	14	67.5%
	9	Excel Formulae	20	43.8%	12	53.6%
Engineering Economics	10	Future Worth	15	21.2%	15	36.7%
	11	Annual Worth	25	3.8%	15	16.1%
	12	Loan Repayment Schedule	35	6.9%	20	5.2%
Homework Policy	13	Homework Policy**	none	none	20	15.7%
		Total*	254	29.2%	191	30.2%

*Total is the sum of the problem averages, not weighted by number of students.
** Content change from 2009 to 2010.

Because of the differences in the exams from 2009 to 2010, quantitative differences cannot be measured accurately between the two. Nevertheless, the exam scores on corresponding problems may be found in Table 8 and used to make some quantitative observations about the adjustments in instruction style. Exam scores are used because there was no Post-Test in 2009.

Table 8. Exam Results 2009 and 2010 for all students

Topic	Problem	Description	2009 Percent	2010 Percent
Engineering Problem Solving Fundamentals	1	Significant Figures/ Scientific Notation/ Metric Prefixes**	89%	67%
	2	Unit Conversions	83%	75%
	3	Order of Operations/ Scientific Notation	61%	75%
	4	Dimensional Analysis	70%	59%
Statics/ Electric Circuits	5	** complete content change	67%	78%
Statistics	6	Descriptive Statistics	77%	74%
	7	Excel Cell References	80%	72%
	8	Reading Graphs	85%	93%
	9	Excel Formulae	94%	90%
Engineering Economics	10	Future Worth	88%	89%
	11	Annual Worth	84%	77%
	12	Loan Repayment Schedule	76%	78%
Homework Policy	13	Homework Policy**	none	85%
		Total*	78%	78%

*Total is the sum of the problem averages divide by total possible on the exam.
** Content change from 2009 to 2010.

Several problems show similar results for the two years including 6, 9, 10, and 12. These include some of the more successful problems, so change in instruction is probably not necessary. Problems 1, 5, and 13 represent content changes instituted for 2010. The addition of metric prefixes to problem 1 increased the difficulty. The change from Statics to Circuits for problem 5 proved to be understood by more students. This is likely due to some students not knowing the trigonometry needed for the statics problem. Problem 13, the FEP Homework policy, was of course a new question. Other discrepancies are likely due to the other changes to grading rubrics.

Conclusion

The Pre-Test, Exam, and Post-Test system can provide significant knowledge about what our students are learning and retaining. The Pre-Tests indicate the base level of our students' knowledge is fairly consistent. By continuing to research how students perform on subsequent exams, we can gain insight into how our teaching strategies and curriculum influence their learning. The hope is that as instructors we can develop our abilities such that our students perform at a successful level on all relevant topics and minimize the amount of class time devoted to material the students already know.

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Biographies

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