AC 2009-5: A UNIVERSITY'S APPROACH TO TEACHING A FRESHMAN-LEVEL INTRODUCTORY COURSE IN INDUSTRIAL ENGINEERING

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A University's Approach to Teach a Freshman-Level Introductory Course in Industrial Engineering

Abstract

An increased emphasis on the development and implementation of freshman-level introductory engineering courses and programs at colleges and universities has occurred in recent years. This is, in part, a response to the increasing shortage of engineering graduates in the United States. These courses and programs are meant to recruit students into engineering and prepare them to successfully study engineering. In many cases, non-standard curricula emphasizing team-based projects are used, and many variations on these themes exist. This paper presents the approach taken by the authors to teach their university's freshman-level introductory course for Industrial Engineering majors. First, published information on and results from freshman engineering courses and programs at various colleges and universities are documented. Then, the approach the authors' university has taken in the past to teach its freshman-level introductory course in Industrial Engineering is presented. This is followed by the motivation for and description of the course's new curriculum, a comparison of student evaluations before and after the curriculum change, and a discussion of future changes for the course's curriculum.

Introduction

As the 21st century begins, the demand for an abundant and talented science, technology, engineering, and mathematics (STEM) workforce remains strong. Continued growth in national productivity requires a continuous supply of professionals who are highly competent in the STEM disciplines and who are adaptable to the needs of a rapidly changing profession.[1] From 2000-2010, employment opportunities in the United States requiring STEM expertise are expected to increase about three times faster than the rate for all other occupations. However, the available domestic STEM labor supply has not and will not be able to satisfy this growth because of the long-term trend of fewer students entering STEM programs in college, thus threatening the ability of U.S. businesses to compete in the global marketplace. The situation is so dire that the National Science Board has stated that the federal government and its agencies must step forward to ensure the adequacy of the U.S. STEM workforce, and that all stakeholders must mobilize and initiate efforts that increase the number of U.S. citizens pursuing STEM studies and careers.[2]

In response to this, many efforts have been established to recruit students into the engineering portion of STEM and to prepare students to successfully study engineering. These efforts have included the development and implementation of freshman-level introductory engineering courses and programs at colleges and universities. The freshman year is very critical for engineering students. Less than half of the students who start in engineering as freshmen eventually obtain an undergraduate degree in engineering.[3] An important factor in this retention issue is mathematics ability as measured by SAT and ACT mathematics scores, mathematics placement tests, and high school mathematics background.[3,4,5,6]

The next section is a literature review of positive results from courses and programs in increasing freshman engineering student retention and mathematics achievement, as well as the documented importance of mathematics in the success of freshman engineering students. These findings legitimize the authors' approach in revising the curriculum of their university's one-semester freshman-level introductory course for Industrial Engineering majors. Following the literature review are sections presenting the approach taken in the past to teach the course, the motivation for and description of the course's new curriculum, a comparison of student evaluations before and after the curriculum change, and a discussion of future changes for the course's curriculum.

The authors' university is Texas A&M University-Commerce. It is a regional university of the Texas A&M University System. It is located in northeast Texas and enrolls approximately 9,000 combined undergraduate and graduate students. A&M-Commerce's Industrial Engineering Bachelor of Science degree was officially established in the Fall 2002 semester and accredited by ABET a few years later.

Literature Review

A number of papers in the research literature document strategies to improve freshman engineering students' mathematical abilities, attitudes toward mathematics, and understanding of the importance of mathematics. Papers from the *2006 ASEE Annual Conference Proceedings* have already been cited and detailed.[4] Other research publications searched were *Advances in Engineering Education*, *ASEE Annual Conference Proceedings* (mostly since 2004), the *Journal of Engineering Education* since 1998, and the *Journal of STEM Education: Innovations and Research*. Most of the following referenced papers detailed strategies that improved the retention and mathematical successes of freshman engineering students.

One paper[7] described a Michigan Technological University effort to help freshman engineering students who were not Calculus-ready and placed into Pre-Calculus. An engineering course was developed to parallel the material in Pre-Calculus. For example, students applied the concepts learned regarding linear, power, and exponential equations in Pre-Calculus to applications in the engineering course. A second engineering course to follow this first one was eventually developed (another paper[8] detailed the development of this engineering course sequence). The first engineering course covered engineering design, engineering ethics, and sustainability in engineering. The second engineering course covered spatial visualization skills, engineering achievements, computer programming basics, and had an engineering design project. Upon completion of the second engineering course, the freshman engineering students placed in Pre-Calculus joined those placed in Calculus in the final engineering course of the first year engineering program.

Another paper[9] documented a Northern Arizona University program called TIMES (Training Intuition in Math for Engineering Success). TIMES started with a pre-test to identify freshman engineering students with inadequate mathematics skills in any of the following six areas: fractions, unit conversion, graphing, systems of equations, exponential and logarithmic functions, and estimation and problem solving. These six areas were identified as important across engineering disciplines. TIMES then involved a guided set of training and practice exercises designed to improve students' abilities in the areas in which they exhibited weakness.

These sessions were conducted by mathematics graduate students. In these sessions, students were provided guidance, help, and training on an individual basis as much as possible. The focus was on the individual student's needs and how the student could achieve the best gains in the topic skills. This was accomplished using the following principles and characteristics of learner-centered education: active learning, student engagement, adaptability focused on individual student needs, practice until mastery, prompt feedback, and general avoidance of the traditional lecture format. TIMES concluded with a post-training skills assessment to determine if any further instruction was needed.

Morrell[10] described the design and implementation of a course in MATLAB computer programming at Arizona State University's Polytechnic campus. This course was deemed necessary because the Calculus courses used MATLAB extensively, and engineering students were experiencing difficulty with it. This paper also cited other MATLAB courses from the literature and documented differences between those courses and the course at ASU's Polytechnic campus. No information was provided regarding the MATLAB course improving engineering student performance in the Calculus courses.

The University of North Texas integrated engineering concepts into the first Calculus course. Engineering and mathematics faculty developed the curriculum for and team-taught this integrated Calculus course. The principles that guided the integration were the illustration of engineering applications, freshmen engineering student contact with engineering faculty, coverage of all mathematical topics covered in other Calculus sections, compatibility for transfer students and students with high school Advanced Placement credit, and flexibility for students who change majors.[11]

Hampikian et al.[12] documented a Boise State University effort to develop engineering courses to be taken concurrently with Pre-Calculus and Calculus. The engineering course taken concurrently with Pre-Calculus utilized a web-based tutorial program called ALEKS[13] (Assessment and LEarning in Knowledge Spaces) for supplemental mathematics instruction. ALEKS offered individualized mathematics tutoring that identified through assessment technology a student's current knowledge and the material a student was ready to learn. The Pre-Calculus Engineering course also had laboratories and advising that included instruction in time-management principles. The laboratories conveyed that engineering was fun, promoted teamwork, and promoted building basic skill levels in laboratory report writing. The engineering course taken concurrently with Calculus also included ALEKS as a major component.

New Mexico State University implemented an Integrated Learning Community (ILC). ILC was a cluster of first-year engineering students who were not Calculus-ready. These students took the same courses their first two semesters to establish a learning community and to allow faculty to integrate concepts in the courses. Supplemental Instruction (SI) was provided for the mathematics courses these first two semesters. SI was identified as a significant contributor to the success of the ILC, as were the opportunity for students to use and apply mathematics concepts and bi-weekly meetings of the instructors to review issues of attendance, motivation, retention, student academic progress, curriculum integration, the status of assignments in progress, and assessment.[14]

North Carolina State University put forth an effort to intervene on behalf of freshman engineering students who performed poorly on their first Calculus exam. The first step was for these students to meet with a College of Engineering academic advisor and develop an Action Plan. The Action Plan was a road map of what these students needed to do between the first and second meetings with the advisor that detailed how the identified and discussed reasons for poor performance on the first Calculus exam would be addressed. The second step was for these students to follow-up on the Action Plan. The third step was for these students to have their second meeting with the academic advisor. The final step was to collect data after the second Calculus exam and assess any actions required. This could involve the establishment of an ongoing Action Plan to increase student learning and success.[15]

Leigh-Mack et al.[16] described a Morgan State University endeavor for freshman engineering students placed into Pre-Calculus. To improve the mathematics success of these students, their section of Pre-Calculus was redesigned based on the Dimensions of Learning (DOL) pedagogy. DOL used what researchers and theorists knew about learning to define the learning process. The optimum approach to teaching and learning was sought. The five dimensions of DOL were positive attitudes and perceptions about learning, thinking involved in acquiring and integrating knowledge, thinking involved in extending and refining knowledge, thinking involved in using knowledge meaningfully, and productive habits of the mind. All five dimensions were addressed in unison. Classes were held in a wireless mobile classroom and students were provided notebook computers with the Discourse software to create an interactive learning environment.

Though it is not the focus of this paper, it should be noted that approaches not focusing solely on mathematics to retain freshman engineering students appear in the research literature. For example, the previously mentioned integrated curricula, computer programming, and learning communities are strategies in and of themselves. Examples of other approaches involve design efforts, projects, and teams[17]; time management and study skills[18]; hands-on laboratory activities[19]; robotics[20]; collaboration with senior-level engineering students[21]; service learning[22]; and research[23]. Various combinations of these strategies may be found in freshman engineering programs as well.[24,25,26]

The Previous Curriculum for the Course

Learning Objectives

Through the Fall 2007 semester (August-December), the one-semester freshman-level introductory course in Industrial Engineering at the authors' university had the following learning objectives students were prepared to demonstrate after completing the course:

1. Knowledge of the traits of a successful engineer, engineering societies, professional registration, and the definition of industrial engineering
2. Knowledge of engineering ethics and their application
3. Knowledge of engineering problem-solving methods and techniques
4. Knowledge of the engineering design method
5. Knowledge of communication methods and applications
6. Knowledge of number notation and significant digits
7. Skill in linear interpolation and the use of software to prepare tables and graphs

8. Skill in the SI units and unit conversion
9. Familiarity with the Industrial Engineering curriculum
10. Familiarity with the location and purpose of the Industrial Engineering and Technology laboratories (equipment and computer)

Source Material

These learning objectives were supported with a primary textbook[27] and two supplementary textbooks[28,29] on reserve in the library. The following chapters and sections were covered in the primary textbook[27] in the order listed using primarily a lecture format:
Chapter 1: Preparing to be an Engineer, Sections 1.1-1.6
Chapter 2: The Engineer, Sections 2.1-2.13
Chapter 3: Engineering Ethics, Sections 3.1-3.7
Chapter 4: Problem Solving, Sections 4.1-4.7
Chapter 5: Introduction to Design, Sections 5.1-5.4
Chapter 6: Engineering Communications, Section 6.1-6.4
Chapter 7: Numbers, Sections 7.1-7.4
Chapter 8: Tables and Graphs, Sections 8.1-8.10
Chapter 9: SI System of Units, Sections 9.1-9.7
Chapter 10: Unit Conversions, Sections 10.1-10.10

Regarding engineering ethics, in addition to the primary textbook[27], the instructor showed internet-based ethics videos developed by the instructor from a funded research project[30]. Students were provided a list of engineering ethics from the National Society of Professional Engineers' (NSPE) Web site[31]. The videos showed scenes acted out in which some of these ethics were violated. Students were asked to list which ethics were violated in each video they were shown.

Graded Work

Homework assignments and tests included problems and questions on the following:
- The history of Industrial Engineering and areas of study within Industrial Engineering
- Performing a literature search for refereed publications
- Graphing in Excel
- Linear interpolation
- The purpose of, Web site for, and student chapter of the Institute of Industrial Engineers (IIE)
- The purpose of the Fundamentals of Engineering (FE) and Professional Engineer (PE) exams and associated professional designations
- The Industrial Engineering curriculum at the authors' university
- The sample mean from statistics
- The future value of a current amount of money from engineering economy
- Constructing and interpreting a Pareto chart
- Engineering ethics
- Different engineering disciplines
- Engineering design
- Teams

- Source information for a Web site
- Accuracy and precision of a measuring system
- Discrete and continuous data
- Percentage uncertainty
- Reading from graphs
- Least squares linear regression

Issues with the Curriculum

During the several years of teaching this curriculum, some issues emerged. First, the curriculum was not preparing students for the different approaches to thinking required in the core mathematics-based Industrial Engineering courses after the freshman year. Specifically, students were having a difficult time with the engineering economy, probability and statistics, and operations research (more specifically, linear programming) courses. Students were getting behind at the start of these courses as they struggled with the new approaches to thinking and the corresponding mathematics. For the rest of the semester they tried to play catch-up, with some of them not succeeding at rates higher than 50% in some offerings of these courses.

Second, Industrial Engineering courses after the freshman year had evolved to the point where they were covering quite a bit of this curriculum at a time when students were more prepared to understand it better. For example, all but the second learning objective was covered at least partially in the sophomore-level Excel and Minitab course, which had Calculus I as a prerequisite.

Lastly, the curriculum was not showing any benefits in retaining students as Industrial Engineering majors. Of the 28 students who completed the Fall 2007 offering of the course, only six, or 21.429%, have remained Industrial Engineering majors. The other 22 included two of the highest-performing students, both of whom initially changed their majors to Mathematics.

The New Curriculum for the Course

Highly motivated by these issues, the authors tasked themselves with developing a new curriculum for the one-semester freshman-level introductory course in Industrial Engineering.

Learning Objectives

For its first implementation in the Fall 2008 semester (August-December), the new curriculum had the following learning objectives:

1. Demonstrate knowledge of Industrial Engineering, related Web sites at the authors' university, and engineering ethics
2. Demonstrate introductory knowledge of matrices
3. Demonstrate introductory knowledge of linear programming
4. Demonstrate introductory knowledge of engineering economy
5. Demonstrate introductory knowledge of discrete mathematics
6. Demonstrate introductory knowledge of probability and statistics

Of the ten learning objectives from the previous curriculum, part of the first and all of the second, third, ninth, and tenth were in the first learning objective of the new curriculum.

Source Material

To support the first learning objective of the new curriculum, the previously mentioned supplementary textbooks[28,29] on reserve in the library were used. Also, the previously mentioned ethics videos again were used in the engineering ethics portion of the new curriculum.

Most of the new curriculum (learning objectives 2-6) was for teaching introductory matrix, linear programming, engineering economy, discrete mathematics, and probability and statistics concepts along with the associated mathematics. This was accomplished using a primary textbook[32] requiring a prerequisite of two years of high school algebra. The following chapters and sections were covered in the primary textbook[32] in the order listed using primarily a lecture format:

- Chapter 1: Linear Functions
  1.1 Slopes and Equations of Lines, 1.2 Linear Functions and Applications
- Chapter 2: Systems of Linear Equations and Matrices
  2.1 Solution of Linear Systems by the Echelon Method, 2.2 Solution of Linear Systems by the Gauss-Jordan Method, 2.3 Addition and Subtraction of Matrices, 2.4 Multiplication of Matrices, 2.5 Matrix Inverses
- Chapter 3: Linear Programming, The Graphical Method
  3.1 Graphing Linear Inequalities, 3.2 Solving Linear Programming Problems Graphically
- Chapter 4: Linear Programming, The Simplex Method
  4.1 Slack Variables and the Pivot, 4.2 Maximization Problems
- Chapter 5: Mathematics of Finance
  5.1 Simple and Compound Interest
- Chapter 6: Logic
  6.1 Statements, 6.2 Truth Tables and Equivalent Statements, 6.3 The Conditional and Circuits
- Chapter 7: Sets and Probability
  7.1 Sets, 7.2 Applications of Venn Diagrams, 7.3 Introduction to Probability
- Chapter 9: Statistics
  9.1 Frequency Distributions and Measures of Central Tendency, 9.2 Measures of Variation

Graded Work

Tests included problems and questions on the following:

- Important people and Web sites in Industrial Engineering
- Definition of Industrial Engineering
- Engineering ethics
- Matrix row operations
- Adding and multiplying matrices
- The future value of a current amount of money from engineering economy
- The graphical solution to a linear programming problem

- Using the simplex method to solve a linear programming problem
- Truth tables (negation, or, and, implication)
- Set operations (complement, union, intersection, empty set) and Venn diagrams
- Probability (sample space, events, set operations on events, probability calculation for equally likely outcomes)
- Sample mean, variance, and standard deviation from statistics

Teaching Approach

In addition to the mathematics, particular attention was paid to the different approaches to thinking associated with matrices, linear programming, engineering economy, discrete mathematics, and probability and statistics. Using the brief description that Industrial Engineers improve processes, students were taught to think of equations as models for processes. The independent variable(s) is (are) the input(s) to the process and the dependent variable(s) is (are) the output(s) from the process.

Systems of linear equations, matrices, and truth tables from discrete mathematics were taught to help prepare students for the computer programming courses and the linear algebra course taught by the Mathematics department. Both of these courses were prerequisites for the first operations research course taught in the Industrial Engineering degree program. It was emphasized that linear programming was mathematical modeling as opposed to statistical modeling, and that both were very useful to Industrial Engineers.

Statistical modeling was emphasized when teaching probability and statistics. The relationship between populations and samples was explained in relation to sets and subsets, respectively. Sets and subsets were taught before probability and statistics. Uncertainty, or variability, with statistical sampling was highlighted along with the idea that probability helps model that uncertainty. With engineering economy, an emphasis was the concept of the time value of money and how interest, both simple and compound, plays an important role in that concept.

Course Evaluation

The same instructor taught the freshman-level introductory course in Industrial Engineering in the Fall 2007 and Fall 2008 semesters (August-December). The standard university course evaluation was administered in both of these offerings of the course. The first part of the evaluation had students answer the following statements with a "1" for strongly agree, "2" for agree, "3" for neutral, "4" for disagree, and "5" for strongly disagree:

1. The professor clearly expresses the objectives for this class.
2. Learning activities (lectures, exercises, etc.) are focused toward achieving the learning objectives in a timely and orderly manner.
3. The professor is always prepared for this class.
4. The tests and assignments in this class were appropriate to the learning objectives.
5. The professor's grading system is fair.
6. The professor returned graded materials within a reasonable time.
7. This professor has increased my understanding of the subject area.
8. The methods of presenting the information have helped me learn the material in this class.

9. The professor integrates current topics or applications of the content area into the class.
10. The professor was receptive to questions in class.
11. The professor was accessible for appointments.
12. The professor has a positive attitude toward students.

The second part of the evaluation had students answer the following statements with a "1" for excellent, "2" for very good, "3" for average, "4" for fair, and "5" for poor:
13. Knowledge of material
14. Presentation skills

Statements 13 and 14 measured teaching effectiveness for the class as compared to other professors at the authors' university in stimulating a student's ability to learn.

Table 1 and Figure 1 show the evaluation results numerically and graphically. The P-value column in Table 1 resulted from testing for a statistically significant difference in the Fall 2007 and Fall 2008 averages for each statement. Using a significance level of 0.05, only the P-values for statements 5, 11, and 12 did not indicate the new curriculum was a statistically significant improvement over the previous curriculum. However, the P-values for the remaining statements strongly concluded that the new curriculum was a statistically significant improvement over the previous curriculum.

Regarding retention, the Fall 2007 offering of the course started with 35 students and finished with 28 students. Six of these 28 students, or 21.429%, have remained Industrial Engineering majors. The Fall 2008 offering of the course started with 42 students and finished with 40 students. Eighteen of these 40 students, or 45.0%, have definitive plans to remain Industrial Engineering majors. Though this percentage is still too low, it is an improvement. This improved retention is attributed to the new curriculum as well as improved efforts since the Fall 2007 semester to recruit and advise Industrial Engineering students.

Table 1. Student Evaluation Results for each Statement (lower avg. is better)

Statement	Fall 2007		Fall 2008		Improvement	P-value
	Responses	Average	Responses	Average		
1	21	1.95	31	1.23	0.73 (37.21%)	0.000
2	21	2.33	31	1.32	1.01 (43.32%)	0.000
3	21	2.00	31	1.19	0.81 (40.32%)	0.000
4	21	1.81	31	1.13	0.68 (37.61%)	0.001
5	21	1.86	31	1.45	0.41 (21.84%)	0.053
6	21	1.57	31	1.23	0.35 (21.99%)	0.018
7	21	2.29	31	1.42	0.87 (37.90%)	0.000
8	21	2.52	31	1.61	0.91 (36.09%)	0.001
9	20	2.40	31	1.74	0.66 (27.42%)	0.015
10	21	1.86	31	1.29	0.57 (30.52%)	0.002
11	21	1.76	31	1.58	0.18 (10.29%)	0.407
12	21	1.90	31	1.52	0.39 (20.40%)	0.099
13	21	2.14	31	1.29	0.85 (39.78%)	0.001
14	21	2.57	31	1.58	0.99 (38.53%)	0.000

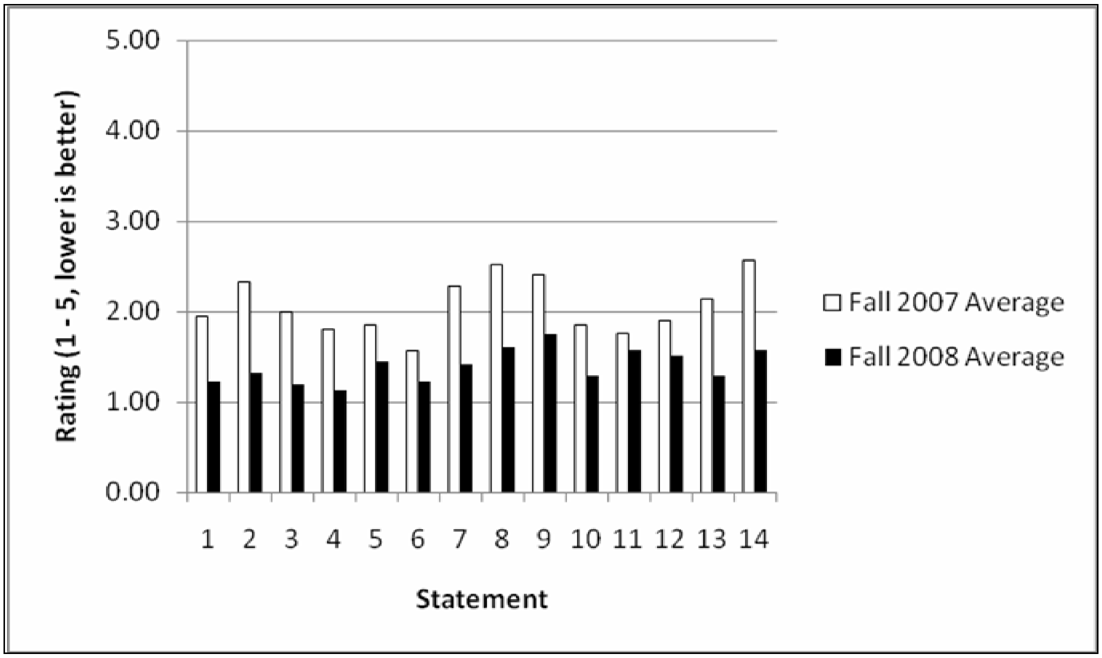

Figure 1. Student Evaluation Results for each Statement

Six students from the Fall 2008 offering of the course had sufficient prerequisites to already have started some combination of the engineering economy, probability and statistics, and operations research courses. Early feedback from these students was positive regarding the new curriculum preparing them for the different approaches to thinking and the associated mathematics in these core mathematics-based Industrial Engineering courses.

Conclusion

This paper presented the approach taken by the authors to teach their university's one-semester freshman-level introductory course in Industrial Engineering. The new curriculum showed improvements in the recruiting, preparation, and retention of Industrial Engineering majors. Also, the new curriculum was presented in sufficient detail to be replicated by other universities.

The authors' university currently has only one engineering degree program, a Bachelor of Science degree in Industrial Engineering. More engineering degree programs will be added in the near future. This will likely require further changes to the freshman-level introductory course for Industrial Engineering majors. For example, information on the new engineering disciplines will have to be added to the first learning objective. It is anticipated that engineering ethics and most of the new curriculum's learning objectives 2-6 will be applicable to the new degree programs.

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