AC 2008-646: ENHANCING STUDENT UNDERSTANDING OF AND INTEREST IN MECHANICAL ENGINEERING

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Enhancing Student Understanding of and Interest in Mechanical Engineering

Abstract

The paper describes an effort to enhance student understanding of the mechanical engineering profession. A freshman course "Introduction to Mechanical Engineering" has been developed with the objective to address such topics as the necessity of good communication skills; professional ethics; the importance of innovation, critical thinking, team work, diversity, and life-long learning. The effectiveness of addressing these issues in a freshman course in comparison with the traditional approach to teaching an introductory mechanical engineering course has been assessed through a study involving student surveys administered in control and pilot class sections at the beginning and at the end of the course. The results of the study demonstrate that the pilot group of students exposed to novel course materials acquired enhanced understanding of the subjects identified by the Engineering Accreditation Commission (EAC) as professional skills.

Introduction

In the past decades, significant strides have been made toward the development and implementation of innovative strategies aimed at achieving excellence in undergraduate science, technology, engineering, and mathematics (STEM) education. Such efforts reflect the overarching vision that the health of the U.S. economy in the 21st century directly depends on the nation's ability to maintain its technological leadership in increasingly demanding, complex, and competitive international markets.

Recent studies conclusively demonstrate that America's technological infrastructure must be transformed in order to maintain "a diverse, competitive, and globally engaged U.S. workforce of scientists, engineers, technologists, and well-prepared citizens." [1-4] As an important measure required to meet these challenges, new engineering accreditation criteria, initially known as Engineering Criteria 2000 (EC 2000), have emphasized the necessity of combining the traditional requirements of rigorous technical preparation, or so-called "hard" skills, and the development of professional or "soft" skills, including such attributes as communication, ethics, critical thinking, and innovation.[5]

The EC 2000 ABET criteria, now part of the Engineering Accreditation Commission (EAC) criteria, have created many new expectations in terms of enhancing, revising, and remodeling engineering programs. In response to new requirements, engineering schools have made consistent efforts to experiment with novel models for baccalaureate education, introducing innovative course curricula. Attention has been focused on first-year college programs with a view to bolster academic performance, stimulate students' interest in the profession, improve retention, and help students clarify, refine, and confirm their career goals. A variety of teaching methods and pedagogical techniques have been developed and implemented for these purposes.[6-9]

This paper describes an effort to enhance student understanding of the issues that form the set of ABET defined professional skills by teaching a novel first-year freshman course "Introduction to Mechanical Engineering." The effectiveness of this approach has been assessed through a study based on two student surveys administered in control and pilot freshman class sections. The surveys were administered in both sections at the beginning and at the end of the course.

Objectives and Approach

The main objective of the reported study is to determine whether a specially designed introductory mechanical engineering course can effectively enhance student understanding of and interest in mechanical engineering. In this pilot course, emphasis has been placed on the following issues:

- Impact and role of technological developments in a global societal context;
- Importance of effective communication skills;
- Multicultural values and diversity in the workplace; and
- Development of professional qualities such as professional ethics, ability to function in multidisciplinary teams, and motivation to engage in life-long learning.

Recent pedagogical research indicates that the first year of students' academic career is critical in terms of shaping student perception and understanding of the engineering profession.[6,10] Very often, misunderstandings regarding career paths, responsibilities, and required professional skills of engineers lead to poor motivation and tend to hinder students' progress in engineering programs. It is important, therefore, that educators adequately address these issues earlier in academic programs.

Guided by this vision, a special freshman course "Introduction to Mechanical Engineering" has been developed at Montana State University as a component of the first-year educational experience. The respective course curriculum has been designed to address the issues raised by the professional skills criteria, which are now included in the Engineering Accreditation Commission (EAC) criteria. The effectiveness of the new course in terms of achieving the stated objectives has been assessed based on two student surveys that followed the guidelines for pedagogical research.[11] Survey I was administered at the beginning of the course in order to determine students' initial knowledge, perception, and understanding of the subjects under consideration. Survey II took place upon the completion of the course, i.e., at the end of the same semester, with the objective to establish any tangible changes in students' understanding of and attitudes toward the same issues.

Student surveys were administered simultaneously in three class sections, a pilot section of about thirty five students, and two control sections with comparable enrollment. Students registered for one of the sections based on their preferred day and time. The pilot section was taught following the novel course curriculum, whereas the course taught in the control sections was based on the traditional approach, focusing primarily on technical mechanical engineering subjects with limited attention to the topics associated with the development of professional skills.

The delivery of course materials in both control and pilot class sections relied primarily on classroom lectures. In the pilot course, this methodology was augmented by specially developed course notes, handouts, required readings, and class discussions. Students were encouraged to express their perceptions, opinions, and attitudes regarding various topics discussed in the classroom.

A comparison of the results obtained from both surveys provided a correspondence between the exposure of students to the identified professional subjects and their self-reported comprehension of and specific interest in the subjects under consideration.

Control and Pilot Courses

The freshman course "Introduction to Mechanical Engineering" has been taught for a number of years within the mechanical engineering program at Montana State University. In the Fall semester of 2007, emphasis in the control class sections was placed primarily on the technical content of the mechanical engineering discipline. Specifically, the course focused on the introduction of the following subjects:

- Mechanics and Materials
- Thermodynamics
- Fluid mechanics
- Heat transfer
- Measurements
- Machines and Electromechanical systems
- Design, and
- Modeling

Limited attention, about 15 percent of the course, was given to such topics as technology and society, engineering ethics, and academic success strategies.

In the pilot section, the course "Introduction to Mechanical Engineering" was taught following an entirely different approach. The course curriculum represented a composition of individual self-contained course modules designed to address various aspects of the mechanical engineering profession. Special attention was given to the issues associated with the development of professional skills, as defined by EAC.

The content of this course can be briefly outlined as follows.[12]

- Module 1. Engineering Profession. (2 hours)

  This module included the following general topics: general definition of engineering, the scope of mechanical engineering, and the career paths of mechanical engineers. Students were encouraged to participate in a discussion that addressed specific topics such as:

"what is engineering," "what do engineers do," and "what do mechanical engineers do." The importance of professional registration and the role of professional societies were emphasized. In conclusion, the top ten achievements of mechanical engineers, as defined by the American Society of Mechanical Engineers (ASME), were discussed.

- Module 2. Technology and Society. (2 hours)

  Course materials developed for this module contained the definition of the term "technology," and a brief history of technological developments from primitive technologies and the invention of the wheel to space exploration and the internet. A classroom discussion concerned the effects of technology on society, the major fields of modern technology, and the role of engineers in technological developments. The latter topic was related to the issues of the societal responsibilities of engineers and professional ethics. The importance for engineers to develop such qualities as humanistic sense, an understanding of societal needs, and the responsibility to act in the best interests of the society was emphasized.

- Module 3. Academic Requirements. (2 hours)

  This module concerned the degree requirements of a typical mechanical engineering college program. Emphasis was placed on the academic mechanical engineering program at Montana State University. In addition, class discussions focused on the importance of extra curricula experiences such as internship, summer employment, research assistantship, teaching assistantship, participation in outreach activities, and active membership in professional student societies.

- Module 4. Engineering, Science and Mathematics. (2 hours)

  This module focused on the connections between engineering, natural sciences, and mathematics. Similarities and differences between science and engineering were discussed and illustrated by specific examples. The term "engineering science" was introduced in the context of new inventions. In this context, the importance of critical thinking and problem solving skills as common qualities of engineers and scientists was discussed.

- Module 5. Engineering Analysis and Design. (2 hours)

  This module included the following topics: basic concepts of engineering analysis; the role of analysis in engineering, the principles of physical and mathematical modeling, the process of engineering design, and the analysis-design connection. Such aspects of engineering design as human factors, safety, reliability, durability, maintenance, and aesthetics were discussed in detail. It was shown that the art of engineering design requires imagination and creativity. This topic was reinforced by specific examples as to how these qualities can be nurtured and enhanced through the acquired knowledge, experience, and skills. In addition, the subject of nature inspired engineering design, defined as biomimetics was introduced.

- Module 6. Engineering Materials. (2 hours)

  This module focused on the use of engineering materials and their role in technological developments throughout the history of civilization from the Stone Age to modern times. Topics included the main classes of engineering materials, their properties, and applications. The basic principles of material selection in mechanical design were discussed. It was demonstrated how the new generations of composite and smart materials have stimulated modern technological advancements.

- Module 7. Professional Skills. (2 hours)

  This module included the following topics: engineering code of ethics; team work; diversity in the workplace; communication skills; decision making skills; creativity and innovation. Students were encouraged to participate in a discussion regarding the challenges and opportunities faced by the engineering profession in the climate of global competition and accelerated technological developments. In this context, attention was focused on the necessity to work in diverse interdisciplinary teams; effectively communicate with fellow engineers, other professionals and general public; make sound decisions; build motivation; and develop self-management and motivation for life-long learning. It was demonstrated that such qualities as creativity and drive for innovation are independent of gender, ethnicity, and socio-economic status.

Student Surveys

The objective of the study reported in this paper was to determine whether the pilot course "Introduction to Mechanical Engineering" described in the previous section would enhance student perceptions about and knowledge of the engineering profession to a greater degree than the traditional course curriculum.

The study was based on two student surveys administered in three (two control and one pilot) freshmen class sections. Teaching of the course in both control sections was identical in terms of the course syllabus and presentation of materials. Both control sections were taught by the same team of instructors and on the same day. The only difference between the control sections was that each was taught at a different time to accommodate student schedules. The pilot section was taught by a single instructor who was not part of the team of instructors that taught the control sections. Ideally, to control for an instructor effect, the same instructor would have taught all three sections; however, teaching assignments prevented this arrangement. All instructors were Mechanical Engineering tenure-track or tenured faculty.

On the first day of classes, all sections were given Survey I. Survey II was administered in all sections on the last day of the course. Student participation in both surveys is shown in Table 1 on the next page.

Table 1. Student Participation

Section	Survey I	Survey II
Pilot	34	25
Control A	35	27
Control B	37	6

The instructor who administered Survey II in the Control B section noted that many of the students in that section did not seem interested in completing the survey. Since participation was voluntary, we had no recourse to obtain more student responses.

The main purpose of Survey I was to determine whether or not all class sections were composed of students we could assume to be from the same population. In addition, the survey included questions designed to gather general information regarding students' perception of the engineering profession and what types of engineering careers students intended to pursue upon graduation. Some questions in the pre-semester survey were taken from the Pittsburgh Freshman Engineering Attitudes Survey.[10] Examples of Survey I questions that addressed engineering professional skills are given in Table 2.

Table 2. Survey I Sample Questions

How important are the following for a successful engineering career: (five-point scale: Very Important = 5, Somewhat Important = 3, Not at All important = 1) Creativity Social skills Strong skills in math and science Ability to work effectively in a team Communication skills Professional ethics
Indicate your level of agreement with the following statements: (five-point scale: Strongly Agree = 5, Neutral = 3, Strongly Disagree = 1) A basic understanding of engineering is important for understanding the world around us. Engineers need to consider cultural values and societal impacts when making decisions. Engineers spend a lot of time working alone. Engineers need to consider cultural values and societal impacts when making decisions.

Survey II contained questions on the same topics as the Survey I, but in some cases the questions were more detailed, as shown in Table 3 on the next page.

Table 3. Survey II Sample Questions

How important are the following for a successful engineering career: (five-point scale: Very Important = 5, Somewhat Important = 3, Not at All important = 1) Professional registration Membership in professional societies Life-long learning Knowledge and compliance with the engineering code of ethics The ability to communicate with people from other cultures and other disciplines The ability to predict the long-term effects of technological developments The ability to work on a team that includes people from other disciplines The understanding of other cultures and cultural differences
Indicate your level of agreement with the following statements: (five-point scale: Strongly Agree = 5, Neutral = 3, Strongly Disagree = 1) Creativity cannot be learned. I can see the benefits of continuing to learn about the role of engineering in society Innovation does not require scientific knowledge. Engineers don't have to understand nature. I can see the benefits of being informed about the broad aspects of engineering. Engineering decisions involve consideration of cultural perspectives and attitudes. Technological developments are influenced by society. Success in engineering depends greatly on personal teamwork skills. Good communication skills may be the most important factor in engineering employment. I would be interested in expanding my knowledge if the societal role of engineering.

Analysis of Results

The results of Survey I were analyzed using the Kruskal-Wallis test. This test is based on a nonparametric statistical method of testing the hypothesis that more than two samples are from the same population and have the same continuous distribution. This non-parametric test was selected because it is not based on the assumption of normal distribution, and provides accurate results when applied to relatively small samples, as in the present case (see references for more detail).[13,14]

The Kruskal-Wallis test showed no significant differences between Survey I responses in all three class sections. It follows that all three surveyed class sections represented the same larger student population with similar attitudes about and perceptions of the mechanical engineering profession.

Because of low student participation for Survey II in the Control B section, as shown in Table 1, and because the first survey had shown no differences among the groups, student responses obtained in the two control sections A and B were combined; thus the results from Survey II were based on a comparison of 25 student responses from the pilot group and 33 responses from combined control groups.

The results of Survey II were processed using the Mann-Whitney test. It is important to note that the Mann-Whitney test is based on the same assumptions as the Kruskal-Wallis test, which was used for Survey I. In fact, the Kruskal-Wallis test represents a generalization of the Mann-Whitney test to three or more groups, whereas the Mann-Whitney test is used for two-group comparisons.

As a rule, statistical differences between groups is represented by a measure of p, which can take values between 0 and 1. The value of p close to 0 indicates statistically significant differences between the groups.[13,14] A typical level of p chosen by researchers to denote significant differences between groups is $p \leq .05$.

Table 4 below shows the results from Survey II for both the pilot and the control groups. Only those results that showed a significant difference between the pilot and control groups are included in the table. Because the Mann-Whitney test is a non-parametric test, it uses medians rather than means. For the Mann-Whitney test, the p value *adjusted for ties* should be used for small samples, and our sample was on the borderline. Generally, small samples would be fewer than 25.

Table 4. Significant Differences Between Pilot and Control Groups on Survey II Responses, Using the Mann-Whitney Test.

Question	Section	Median	*p* Value	*p Value* Adjusted for ties
How important is [Professional Registration] for a successful engineering career?	Pilot Controls	5 4	.044	.028
How important is [The ability to communicate with people from other cultures and other disciplines] to a successful engineering career?	Pilot Controls	5 4	.014	.006
What is your level of agreement with the statement: "I can see the benefits of continuing to learn about the role of engineering in society"?	Pilot Controls	5 4	.081	.050
What is your level of agreement with the statement: "Technological developments are influenced by society."?	Pilot Controls	5 4	.019	.007
What is your level of agreement with the statement: "Engineers don't have to understand nature."? (low score would indicate disagreement, and thus a positive response)	Pilot Controls	1 2	.021	.009

As shown in the table above, student responses to the following questions proved significantly different, as shown by the probability level *p* adjusted for ties. The values of $p \leq .05$ or less were obtained in regard to the following questions:

- Level of importance of professional registration (pilot section placed higher importance)
- Level of importance of the ability to communicate with people from other cultures and other disciplines (pilot section placed higher importance)
- Level of agreement with the statement "I can see the benefits of continuing to learn about the role of engineering in society" (pilot section showed stronger agreement).
- Level of agreement with the statement "Technological developments are influenced by society" (pilot section showed stronger agreement)
- Level of agreement with the statement "Engineers Don't Have to Understand Nature" (pilot section showed lower agreement)

Note that the responses to one of the questions (I can see the benefits of continuing to learn about the role of engineering in society) did not show a significant difference between control and pilot groups at a $p \leq .05$ probability level when *not adjusted for ties* ($p = .081$). For the Mann-Whitney test, the *p* value *adjusted for ties* should be used for small samples, and our sample was on the borderline.

Results (*p* values when *adjusted for ties*) from the Mann-Whitney test for some of the other survey items are shown below:

- Level of importance of being a member of a professional society ($p = .34$)
- Level of importance of the knowledge of and compliance with the engineering code of ethics ($p = .98$)
- Level of agreement with the statement "Engineering decisions involve consideration of cultural perspectives and attitudes" ($p = .10$)
- Level of agreement with the statement "Success in engineering depends greatly on personal teamwork skills ($p = .34$)

These results indicate that there was not a significant difference between the pilot and control groups on these questions ($p \leq .05$). For all of the questions above, both groups responded equally strongly in the positive, e.g., the median score for the level of agreement to the question "Success in engineering depends greatly on personal teamwork skills" was 4 on a scale of 5 (Somewhat Agree).

Based on the results from both student surveys, it is clear that the pilot course curriculum has made a tangible difference in student perceptions and understanding of the following subject areas:

1. The importance of professional registration
2. The relationship between engineering design and nature
3. The relationship between technology and society, and

4. The importance of effective communication with people from different cultures.

In addition, the responses to the question “I can see the benefits of continuing to learn about the role of engineering in society” bordered on a significant difference between the pilot and control groups.

The significant difference between the groups in terms of the responses to the question about “communicating with people from other cultures” is somewhat weakened by the fact that the difference between the responses to a similar question: “How important is the understanding of other cultures and cultural differences for a successful engineering career” was not significant.

Conclusions and Future Research

The study reported in this paper concerns the effectiveness of an innovative freshman-level course “Introduction to Mechanical Engineering” with emphasis on the set of professional skills defined by ABET EC 2000, now included in EAC criteria. The study was based on two student surveys administered in three (two control and one pilot) freshmen class sections.

In the control class sections, emphasis was placed primarily on the technical content of the mechanical engineering discipline, whereas the pilot course curriculum was designed to address various aspects of the mechanical engineering profession, focusing on the importance of professional skills. The latter approach required special preparation, including the development of course notes, examples, and illustrations, using a variety of sources such as encyclopedia, books, articles, and electronic materials.[12] At present, the developed course notes can be used by other instructors interested in following a similar approach.

The surveys administered at the beginning and end of the 2007 fall semester provided information regarding the effectiveness of the piloted course curriculum in comparison with the more traditional freshman course. The results of the surveys demonstrated that student perceptions about the importance of professional registration were higher in the pilot group. Students in the pilot group also showed greater appreciation for the importance of the ability to communicate with people from other cultures, the importance of understanding nature for effective engineering design, and the relationship between technology and society. These results can be attributed to higher emphasis on the respective issues in the pilot course.

It is important to note that the reported study represents the first pedagogical experiment involving the freshman mechanical engineering course at Montana State University. It is expected that further refinement of the course content will provide additional benefits, increasing the effectiveness of the described approach. It would be of interest to expand the present study in order to investigate whether student understanding of the engineering professional issues gained in an introductory freshman course would have a long-term effect in terms of students' perceptions of engineering, their academic success, and motivation to pursue engineering careers.

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References

[1] "Transforming America's Scientific and Technological Infrastructure. Recommendations for Urgent Action," *Report on Reports II, Project Kaleidoscope*, 2006. (http://www.pkal.org/documents/RepotonReports.pdf)
[2] Bok, D., "Our Underachieving Colleges," Princeton University Press, 2006.
[3] "Educating the Engineer of 2020," *Report of the National Academy of Engineers*, The National Academic Press, Washington, D.C., 2001. (http://www.nap.edu/books/0309096499/html)
[4] "Investing in America's Future," NSF Strategic Plan, FY 2006-2011, NSF 06-48, Sept. 2006.
[5] Shuman, L. J., Besterfield-Sacre, M, and McGourty, J., "The ABET "Professional Skills" – Can They Be Taught? Can They Be Assessed?" *Journal of Engineering Education*, Vol. 94, No. 1, 2005, pp. 41-55.
[6] Brannan, K. P., and Wankat, P. C., "Survey of First-Year Programs," *Proceedings, 2005 American Society for Engineering Education Annual Conference and Exposition*, ASEE, 2005.
[7] Dimitriu, D. G., and Karimi, A., "Exploring Engineering Profession – A Freshman Engineering Course," *Proceedings, 2005 American Society for Engineering Education Annual Conference and Exposition*, ASEE, 2005.
[8] Turns, J., Atman, C. J., Adams, R. S., and Barker, T., "Research on Engineering Student Knowing: Trends and Opportunities." *Journal of Engineering Education*, Vol. 94, No. 1, 2005, pp. 27-40.
[9] Wickert, J., "An Introduction to Mechanical Engineering," 2nd edition, Thompson, 2006.
[10] Besterfield-Sacre, M.E., C.J. Atman, and L.J. Shuman, "How Freshman Attitudes Change During the First Year," *American Society for Engineering Education Conference Proceedings,* June 1995, pp. 157-163.
[11] Fraenkel, J. R., and Norman, E. W., "How to Design and Evaluate Research in Education," McGraw Hill, 1993.
[12] Vinogradov, A. M., "An Introduction to Mechanical Engineering," Course Notes, MSU, 2007.
[13] Gibbons, J. D., and Chakraborti, S., "Nonparametric Statistical Inference," 4th edition, CRC, 2003.
[14] Wasserman, L., "All of Nonparametric Statistics," Springer, 2007.