AC 2011-1173: ASSESSMENT OF SOFT-SKILLS-PROGRAM LEARNING OUTCOMES USING ENGINEERING COURSES

Thomas J. Vasko, Central Connecticut State University

Thomas J. Vasko, Assistant Professor, joined the Department of Engineering at Central Connecticut State University in the fall 2008 semester after 31 years with United Technologies Corporation (UTC) where he was a Pratt & Whitney Fellow in Computational Structural Mechanics. While at UTC, Dr. Vasko held adjunct-instructor positions at the University of Hartford and RPI Groton. He holds a PhD in ME from the University of Connecticut, an MSME from RPI, and a BSME from Lehigh University. He is a licensed Professional Engineer in Connecticut and he is on the board of directors of the Connecticut Society of Professional Engineers. He also holds memberships in ASME and AIAA.

Nidal Al-Masoud, Central Connecticut State University

Dr. Al-Masoud, Associate Professor, earned his Ph.D. in Mechanical Engineering from The University at Buffalo, The State University of New York in 2002. Dr. Al-Masoud has taught at both graduate and undergraduate level courses at University at Buffalo, he joined Central Connecticut State University as an Assistant Professor in 2003. At CCSU, he teaches courses at all levels in the three major areas in mechanical engineering, namely: mechanics, Thermo-fluid, and Control Systems and Dynamics. Dr. Al-Masoud research interests are in the fields of Control Systems and Dynamics, HVAC systems, and Engineering Education. He has numerous journal and conference proceeding publications in the aforementioned area, and was the winner of the ASEE Mechanics Division Best paper Award in 2006. He has an extensive experience in Heating Ventilation and Air Conditioning Systems (HVAC) design. Dr. Al-Masoud is very active in many Professional Societies. He serves on the Board of Directors of American Society of Mechanical Engineers, Hartford Section; he is also the Faculty advisor of CCSU-ASME Student section. He is a member of the American Institute of Astronauts and Astronautics (AIAA), IEEE, ASEE.

Peter F Baumann, Central Connecticut State University

PETER F BAUMANN is an Associate Professor in the Engineering Department at Central Connecticut State University. Dr. Baumann received a B.S. in Metallurgy at Penn State, earned an M.S. from MIT Mechanical Engineering, and completed a Ph.D. in Materials Science at Polytechnic University. His industrial experience spans 20 years.

Assessment of Soft-Skills for Student Outcomes Using Engineering Courses

Abstract

ABET's criterion requires engineering students to possess several technical "hard skills" as well as nontechnical "soft skills" upon their graduation, with the former learning outcomes typically easier to evaluate and assess than the latter. This paper presents rubrics and assessment methods using engineering courses for evaluating the soft-skills-program learning outcomes engagement in lifelong learning competencies, communication, and the impact of engineering solutions. The assessment of the lifelong learning student outcome is addressed using results from a set of semester-long assignments in a fluid mechanics course. The recently developed and adopted course, Engineering Technical Writing and Presentation, in which students learn to develop an effective writing process for writing engineering documents in future courses and industry, is used in the assessment of competencies in effective oral and written communication skills. The senior capstone project, which typically assesses teamwork, now requires students to write an impact statement that is used in the assessment of skills such as identification of need and the positive and negative impacts on humankind, environment, and economy. Rubrics to assess and evaluate these soft-skill learning outcomes, along with findings from the current semester where available are presented in the paper.

Introduction

Over the years, the engineering profession and engineering education has changed and evolved to meet technological, economical, workforce, global, and societal challenges. Several national organizations such as the National Academy of Engineering (NAE)[1] and the Accreditation Board of Engineering and Technology (ABET)[2] have taken proactive steps to address and respond to these challenges in various forms. The NAE report "The Engineer of 2020, Visions of Engineering in the New Century" [1] addressed the technological, societal, and global contexts of the engineering practice and their implications on engineering education. The report concluded with a set of desirable attributes in the future engineering workforce. Many of these attributes will be similar to the past and current attributes, but are made more complex by the impact of new technology[1]. Strong analytical skills, practical ingenuity, creativity, communication, high ethical standards, professionalism, and lifelong learners are examples of NAE aspirations.

In developing what is currently known as Engineering Criteria 2000, ABET reaffirmed a set of "hard" engineering skills, while introducing a second, equally important, set of six "professional" skills. These latter skills include communication, teamwork, and understanding ethics and professionalism, which are designated as process skills; and engineering within a global and societal context, lifelong learning, and knowledge of contemporary issues, which are designated as awareness skills[3]. While it is traditionally easy to measure and evaluate hard skills through mathematics, science, technology, and engineering courses, assessment of soft-skills poses some challenges to engineering educators. In this paper, we present our experience in using engineering courses to address the soft skills lifelong learning, communication, professional and ethical obligations, and the global impact of engineering.

Lifelong Learning Outcome

The fast pace of advancement in science and technology makes it vital for all professionals to stay up-to-date with contemporary advances and innovations in various fields of technology. The multidisciplinary nature of engineering practice puts engineers at the forefront of meeting this pressing demand. At some point in their practice, engineers will need to solve a problem or design a component that requires research, learning new software, knowledge of other engineering disciplines, or locating an article in a book, journal, or conference proceeding.

Criterion 3i of the EAC 2000 states the expectation that engineering graduates must have "*recognition of the need for, and an ability to engage in lifelong learning*." The theme of this criterion is to instill the ability to learn how to learn. Philip Candy[4] defined lifelong learning as "*equipping people with skills and competencies required to continue their own self-education beyond the end of formal schooling.*" In a memorandum on lifelong learning, the Commission of the European Communities defined lifelong learning as an "*all purposeful learning activity, undertaken on an ongoing basis with the aim of improving knowledge, skills and competence*"[5]. A survey of 35 students in a fluid mechanics course was conducted at the end of the fall 2010 semester with 27 students responding. In the survey, students were asked to provide their definition of lifelong learning after receiving the aforementioned Commission of the European Communities definition. The following are selected verbatim responses grouped according to their level of understanding with the supplied definition.

A. Fully Understand

1. "The ability to research and understand new material."
2. "The ability to constantly gain knowledge and apply it."
3. "Lifelong learning is a person's lifelong process of acquiring knowledge and/or skills."
4. "A learning experience that grows with time that increase skills"
5. "To learn things one will use in the future and to be able to continue to learn outside the classroom."
6. "Lifelong learning is the seeking out of new information with the goal of increasing your proficiency in activities relative to your personal or professional life. This proficiency is potentially beneficial to those around you that rely on your skills and knowledge."
7. "Lifelong learning should be something we take out of class and learn it and relate it to the class. Also, I believe it is more out of subject research which helps. It helps develop interest to various topics."

B. Understand

1. "Personal development, improve upon what you've learn so far, and working with others to achieve any particular tasks or goals, and continuous learning"
2. "Continuing research on a topic of interest"
3. "To be able to apply what is learned to everyday life"
4. "A chance for someone to show what knowledge they possess in regards to a particular subject matter. Or being able to demonstrate the ability someone may have in information gathering through observation, research, and report writing."
5. "Learning is never enough."
6. "Lifelong Learning means to learn as you go through life (personal experiences)."

7. “A research project, which enhances one's knowledge of a particular field, and how it relates to my expectations/perceptions.”
8. “It's like a research paper, except it attracts students' interests, and makes them want to pay more attention to the topic.”
9. “Learning that is embedded in mind even after a certain subject is over.”

C. Somewhat Understand

1. “A project that has some effect on your life, whether it be understanding material better or something for your career”
2. “Learning something that will help you later in life not just learning something and using it for the test.”
3. “Life Long Learning is learning something that will be useful for the rest of your life. Something that you can acquire knowledge about for an extended period of time. Perhaps some subject that interests you that you keep learning about.”
4. “it is daily knowledge acquired by the learner that involve experience or anything that exist throughout individual life”

D. Do Not Understand

1. “Problems that provide a sufficient knowledge for the student about a particular subject in Fluid Mechanics.”
2. “Lifelong Learning is the idea of being taught something that will remain with you and help you throughout the rest of your career, academic or professional.”
3. “Computational Fluid Dynamics was originally used as a research tool in the aerospace industry. It has since moved to be used as a design tool. Find what other industries make use of CFD and record your findings in a brief report.”
4. “something learned that stays with an individual throughout their lifetime”
5. “Blood and ferro-fluids as non-Newtonian fluids”
6. “A problem whose solution remains unsolved for a long time or which never gets a definite answer and there is always room for improvement.”
7. “My definition of lifelong learning is increasing my knowledge of the advancements in medical care and understanding where it originated.”

Felder[6,7] divided lifelong learning outcome into two parts. The first part is the recognition of the need for lifelong learning which, according to Bloom’s[8] taxonomy of educational objectives, is governed by the attitudes and values that strongly influence the behavior of the learner and are better known as the “affection domain”[8]. There are several levels of competency in this domain including, stimulating the students’ interest in a certain area, students’ response and attitude to this stimulus, and development and implementation of a systematic approach to learning. The second part is the ability to engage in lifelong learning which, according to Bloom’s[9] taxonomy of educational objectives falls under the “cognitive domain”. The mastery of this part is governed by several actions that, in general, focus on the students’ ability to explore new ideas, demonstrate comprehension, arrive at solutions, generate new ideas, and, finally, judge the feasibility and value of these solutions or new ideas.

Lifelong Learning Outcome: Assessment Process

As previously mentioned, a fluid mechanics course was used as a data source for assessment purposes of the lifelong learning student outcome. This is the first time this course has been utilized in our department as a source of data to measure the attainment of the lifelong learning outcome. The initial attainment level is measured through two performance indicators as follows:

1. Recognize the attributes of a lifelong learner and the significance of lifelong learning, and identify sources for continuing education
2. Perform in-depth analysis, produce quality work, and use various resources to learn new material independently

The choice of a fluid mechanics course is based on the interdisciplinary nature of this subject. Fluid mechanics plays a fundamental role in a wide range of applications in almost all fields of engineering disciplines. In fact, it is difficult to think of any process, machine, device, or tool that doesn't have some application of fluid mechanics buried in it or behind its design and operation. This junior level course is offered to a mixed population of mechanical and civil engineering students, with the course being a prerequisite for many courses for both majors.

Towards the middle of the semester, students were given a set of twenty seven open-ended problems provided at the end of each chapter in their text book[10]. The project was to be conducted in teams of two students; however, some teams opted to have three students and, in such a case, additional work was required. Each team was to pick one topic from the available pool of twenty seven topics on a first-come-first-served basis, since duplication was not allowed. Information sources were restricted to peer-reviewed published work such as journal articles, conference proceedings, and books. Students were directed to use the main engineering digital database, the Engineering Village, or the Compendex, which provides a comprehensive coverage of literature in all engineering fields. Unsupported assertion or claims were a basis of rejection or grade reduction of the project grade.

A wide range of topics were covered, including medical applications, sports, hydraulic machines, weather, and flow measurement devices. The topics covered included:

A. Lab on a Chip: Principles, Functionality, and Operation of Various Components
B. Man-Made Non-Newtonian Fluids: Study of the development of different types of fluids to understand blood flow, heart related, and cancer treatment
C. Liquid Jet Cutting Technology and Applications
D. Deteriorating Dams
E. Dams structures
F. Wind flow effects on tall structures
G. Design and Manufacturing of Pitot tubes
H. CFD applications
I. Non-Petroleum based lubricants
J. Preliminary design of turbomachines rotors
K. Swimming efficiency and improvement
L. Usefulness of the submerged Lumber

It is obvious that all these topics are, to differing degrees, fluid mechanics related and very few are directly covered in traditional undergraduate course in fluid mechanics. At the undergraduate level, one should not expect a cutting edge finding; however, students did express their satisfaction and gratitude for doing something other than regular homework, exams, and lab work. As an example, after completing research on design of turbo-machine rotors, a mechanical engineering student wrote "*as an engineer, I found this subject the most fascinating of all other engineering studies. I enjoyed learning more about this project, and would consider turbomachinery as a concentration for a master degree in the future.*" In another example, after investigating wind flow effects on tall structures, a civil engineering student wrote "*This subject is ideal for my major, as I am a civil engineer. Since I am doing my internship in a structural engineering firm, and structural engineering is what I hope to do as a career once I graduate, wind pressure study on buildings are very important to me and my future success.*"

Lifelong Learning Outcome: Analysis, Observations, Lessons Learned, Future Outlook

The purpose of the online survey conducted at the end of the semester is to identify students' reflections on the lifelong learning exercise from the perspective of their ability to recognize the attributes of a lifelong learner, to understand the significance of lifelong learning, and to learn new material on their own. In addition, opportunities for improvement to and expansion of the project tasks are explored.

Figure 1 shows the students' response to being involved in any research initiative during their academic career. It is obvious that the vast majority of students were not involved in any type of research oriented projects and certainly not an initiative where they learn on their own. Such an initiative, therefore, could be very valuable to students prior to their senior capstone project. It also highlights the need to instill the mentality of knowledge seeking outside the class classroom early in the engineering program. For example, students in the freshmen level Introduction to Engineering course currently work on a team project developed from concepts presented in the class. Expanding the project to require use of engineering principles not presented in class would necessitate students learning early in their academic career how to learn on their own.

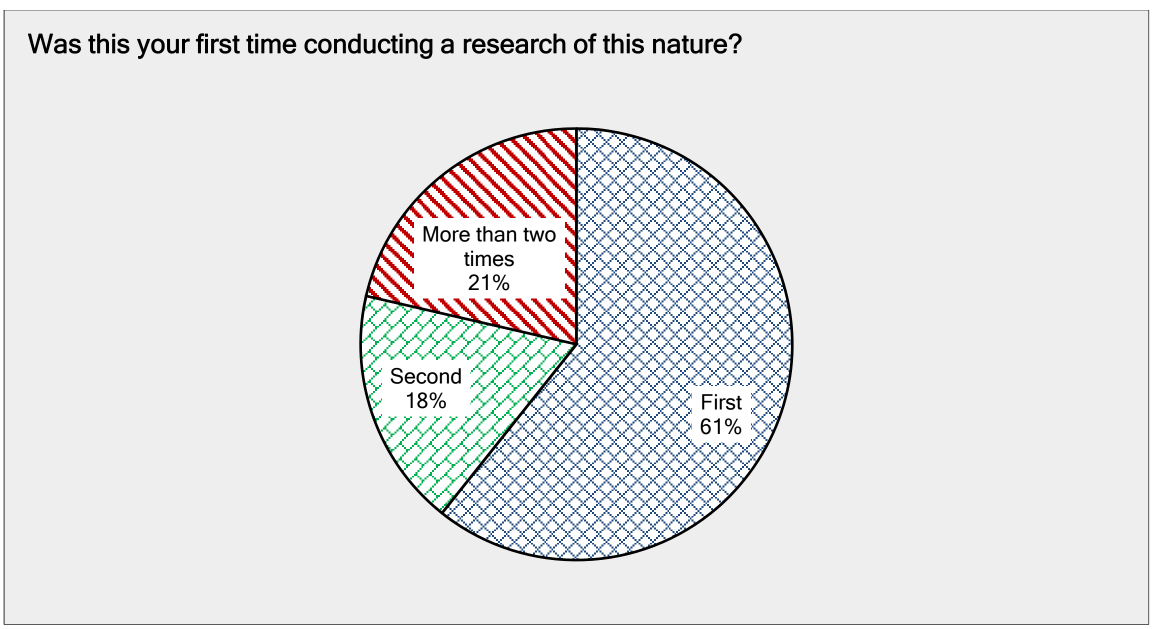

Figure 1: Students involvement in research type assignments

Figure 2 shows the enthusiasm level of the students towards the project. The vast majority of students valued the experience, which may be a result of their awareness of the significance of lifelong learning.

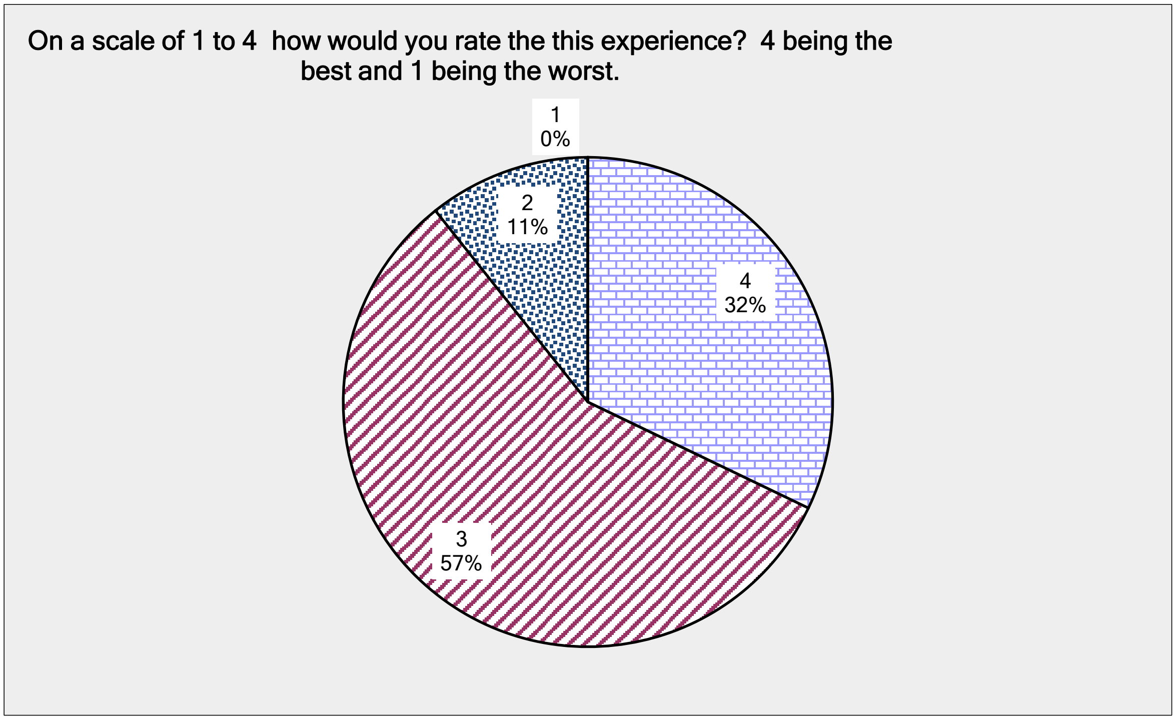

Figure 2: Rating of the lifelong learning experience

Figure 3 shows students recognition of the attributes of a "lifelong learner". These attributes and skills are based on the "Foundations and Skills for Lifelong Learning Value Rubric"[11]. The rubric is part of the "Valid Assessment of Learning in Undergraduate Education (VALUE)"[11] sponsored by the Association of American Colleges and Universities. The study cited five skills, as shown in the figure, that a lifelong learner must possess: curiosity represents the depth of exploration; initiative measures the ability to generate new ideas or solutions; independence is an indicator of self-learning; transfer appraises the ability to build on previous knowledge; reflection is "in depth reviews of prior learning experiences both inside and outside of the classroom to reveal significantly changed perspectives about educational and life experiences"[11].

The purpose of the survey question was to explore the mindset of students about these required skills. While most students agree, in general, that all of these skills are fundamental to a lifelong learner, it was surprising that one third of the class downplayed independence when compared to the other attributes. This can be explained by the fact that 61% of the students have never been involved in such an experience as shown in Figure 1.

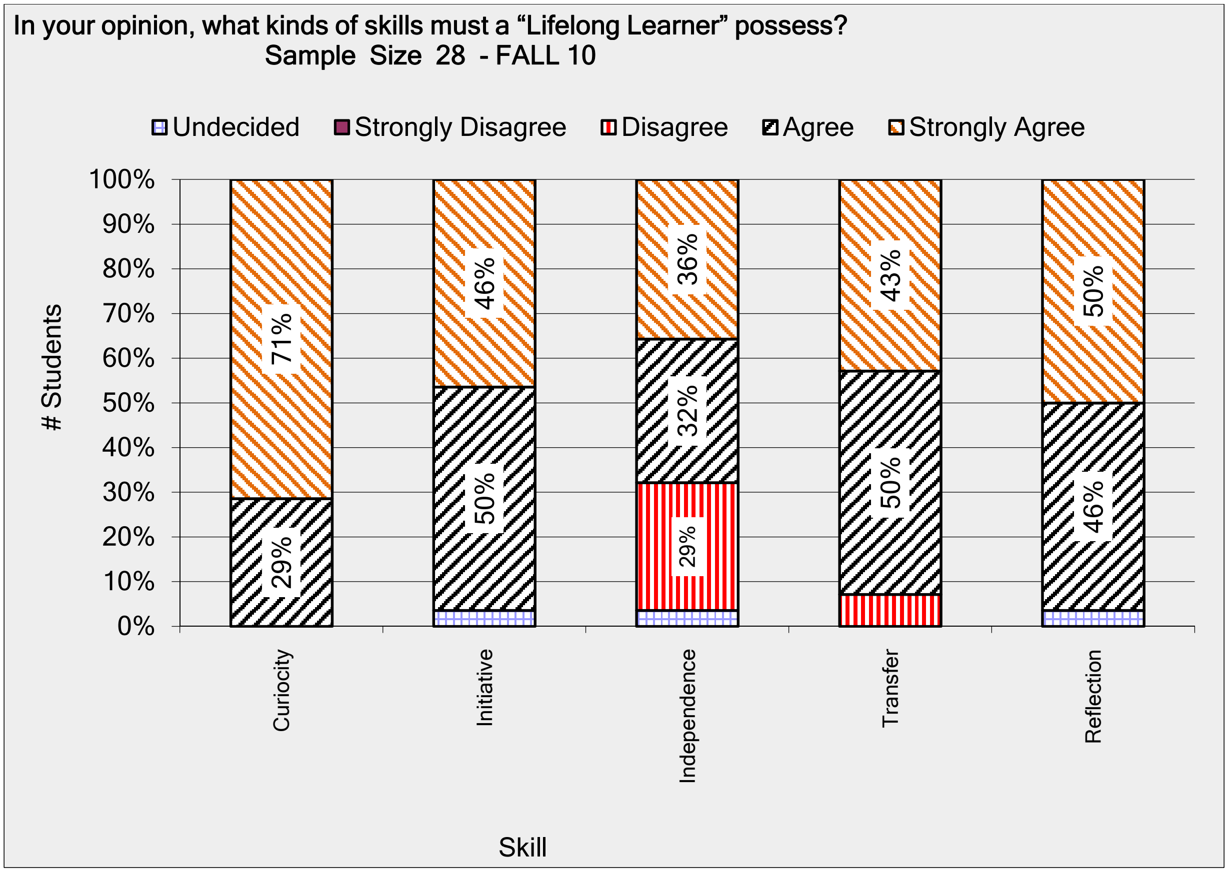

Figure 3: Lifelong learner required skills - students' perspective

The final part of the survey was a set of seventeen questions to assess the effects of the "learn how to learn" skill as a result of completing the research project. Some of these questions are implicitly linked with the "VALUE" lifelong learning attributes. Table 1 and Figure 4 show the set of questions and the survey results, respectively. The positive responses (significantly improved and improved) outweighed the negative responses (unchanged or unsure) by a ratio of four to one (4:1). Although the sample size is too small for any significant statistical inference, these results show that students do not believe they are well prepared in most of these categories.

Table 1: Learning Trends Changes

Estimate the degree to which your ability to successfully complete the tasks listed below changed as a result of conducting the research on your own					
	Answer Options	Significantly improved	Improved	Unchanged	Unsure
Q1	To realize the breadth and width of fluid mechanics applications in life sciences, physical sciences, astrophysics and geosciences, and all fields of engineering.	14	13	1	0
Q2	To learn topics not taught in the classroom on my own	9	16	3	0

Q3	To determine how much information is needed to answer a research focus question.	7	17	4	0
Q4	To know how to select appropriate keywords for searching Engineering Village, Compendex or other databases effectively.	11	11	6	0
Q5	To revise my selection of keywords to find information more efficiently.	12	7	8	1
Q6	To accurately summarize relationships between the main concepts discussed in an article.	9	12	7	0
Q7	To construct new concepts from my analysis of concepts discussed in an information source.	6	18	4	0
Q8	To identify contradictions, when they occur, in an information source.	4	17	7	0
Q9	To find and apply a review article to validate my understanding of a primary research article.	5	20	3	0
Q10	To make diagrams that accurately and clearly shows relationships among concepts.	6	11	10	1
Q11	To apply new and prior information to creating a written report on a specific issue.	5	15	8	0
Q12	To cite (acknowledge) all sources of information I include in my reports.	9	9	10	0
Q13	To understand journal articles written by scientists about their research experiments and theoretical findings.	12	14	2	0
Q14	To question the validity of information, including that from textbooks or teachers.	7	13	7	1
Q15	To distinguish fact from opinion, belief, and unsupported claims.	6	18	4	0
Q16	To explain in a clear manner a scientific concept or procedure to other people.	8	12	8	0
Q17	To evaluate my own writing assignments before turning them in for grading.	5	12	10	1

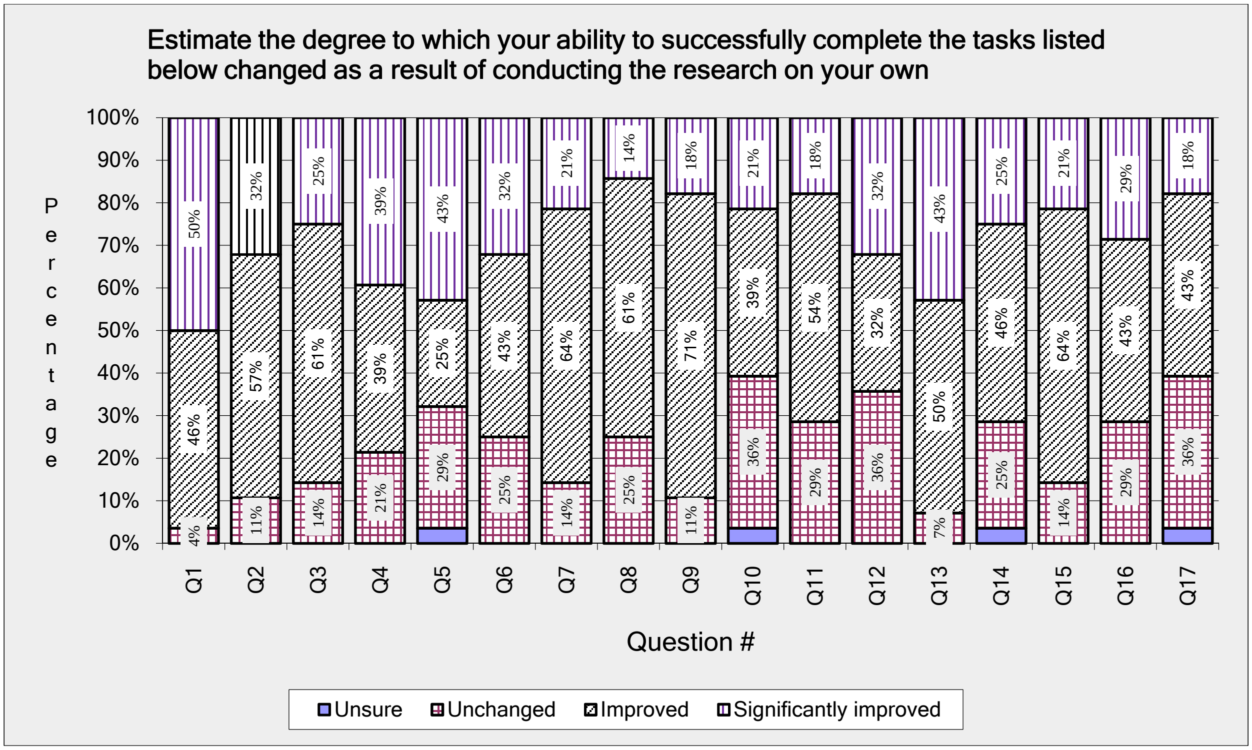

Figure 4: Learning trend changes

In terms of the performance indicators mentioned above, many students were able to recognize the attributes of lifelong learners as shown in Figure 3; however, putting it into practice was a different issue. On the positive side of the spectrum, the project exposed students to a set of vital skills necessary to be a successful graduate student, practicing engineer, or graduate student. These include but are not limited to effective literature reviews from peer reviewed published journal and conference proceedings, the use of electronic databases, and the interlibrary loan program. Additionally, students practiced validating information by distinguishing facts from opinions or unsupported assertions. Team work, and written communication skills were also practiced. On the other side of the spectrum, however, review of the written reports revealed some shortcomings and concerns that need to be addressed. Specifically, many reports lacked proper analysis, synthesis, and logical conclusions and did not convey students' understanding and shaping of the whole work. In fact, some reports were merely a pure literature review with no input and discussion. Therefore, the second performance indicator was minimally attained.

To achieve a better attainment level of this second performance indicator, the department will continue using this approach of learning, practicing, and demonstrating lifelong learning skills and will expand it to other courses such as the previously mentioned Introduction to Engineering course and the Finite Element Analysis course, where students will be asked to explore the literature for published solutions to real engineering problems using the finite element method. In addition, many of the shortcomings in technical report writing will be addressed in the newly introduced engineering writing course discussed in the following section.

Communication Outcome

The ability to communicate effectively in written, oral, graphic, and electronic means is vital to the success of engineers, and it is identified as a learning outcome in the ABET criteria. A focus group composed of graduating seniors and the Industrial Advisory Board, a group of representatives from local industries that meets once a semester to evaluate and to make recommendations for enhancing the Mechanical Engineering program, identified deficiencies in communication skills of engineering graduates. The focus group concluded that the current required courses of Technical Writing offered by the English Department and Public Speaking offered by the Communications Department were not improving the graduates' ability to produce the broad range of engineering documents and the types of focused engineering presentations required to meet the expectations of their employers. Specifically, the graduates lacked ability to produce clear, concise, organized, readable, error-free documents making use of relevant sources with proper citations. In addition, the graduates were deficient in competencies to prepare audience-appropriate presentations based on their engineering work.

As a result, a new engineering course, Engineering Technical Writing and Presentation, was developed by the Engineering Department to address shortcomings in students' ability to write a broad range of engineering documents and deliver effective audience-appropriate engineering presentations. One of the challenges with this course is that most students in engineering courses learn by solving problems; i.e., they learn by doing. They first learn theory and the application of the theory by solving sample problems in the classroom and in their textbooks. The students further enhance their understanding of the theory and problem-solving ability in related homework problems and, finally, examinations evaluate the extent of the students' understanding. It is unreasonable, however, to expect students to produce the broad range of engineering documents in a single technical-writing class given time constraints; and, more importantly, without an engineering context for those documents, such assignments will be of limited value. The focus of the new writing course, therefore, is to develop and to present effective strategies, outlines, and checklists for writing each type of engineering document, as well as to review and evaluate these outlines and checklists in examples and assignments. Where appropriate, students will also be required to write engineering documents and deliver engineering presentations, but the focus of the course will be on developing techniques and guidelines so that in future courses and in industry the students will be well prepared to produce the required engineering documents.

An additional component of the class, aimed directly at the students and their desire to seek an internship or industry employment after graduation, will focus on the writing of resumes and cover letters. Students will learn strategies for writing a resume and for tailoring the resume to apply for a specific job. A presentation component will also require students to develop an overview presentation based on their resume for use in a job interview.

The assessment rubric shown in Table 2 has been developed to gauge the students' ability to produce engineering documents and to give engineering presentations for a specific audience. This rubric will be used by students at the end of the semester to enable them to gauge the degree to which they have improved in their ability to recognize audience and complete the range of engineering documents. This new course is being offered for the first time in the spring 2011 semester and, therefore, a future paper will present the results.

Table 2: Communication Assessment

Estimate the degree to which your ability to successfully complete the task listed below changed as a result of completing the course				
	Significantly Improved	Improved	Unchanged	Unsure
To recognize the importance of effective engineering communications				
To recognize the importance of audience in engineering communications				
To develop an audience-appropriate presentation				
To speak in front of an audience				
To produce each of the following engineering documents:				
Mechanism Description				
Process Description				
Informal Proposal				
Formal Proposal				
Progress Report				
Feasibility Report				
Recommendation Report				
Lab Report				
Project Report				
Instructions				
Manual				
Research Report				
Abstract				
Summary				
Journal Article				
Website				
E-Mail				
Resume				

Impact of Engineering Solutions Outcome
To address and assess the ABET Program Outcome requiring "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context", the University, within its senior capstone final report, has added an impact statement as a required discussion subsection. Nestled between general discussion considerations and directions for future work, the current impact statement requires students to offer commentary on four effects: environmental; health and welfare; societal and economic; and governmental and political.

Gathering, reviewing, and implementing recommendations contained on Materials Safety Data Sheets (MSDS) for materials consumed during the project build phase can be outstanding steps in establishing both environmental, and health and welfare effects. In addition to material identification and some chemical and physical property information, these documents address the safe handling and waste disposal methods related to the environmental impact. Fire, explosion, reactivity, and health hazard information coupled with recommended control measures and emergency first aid procedures support our health and welfare review. Obtained MSDS's can ultimately be housed in an appendix of the final report. Additional environmental and health and welfare effects will also be a consequence of the actual created designs necessitating further overall reflection.

The practice of putting scientific knowledge to practical use within the engineering design process supports the listing of societal benefits (and detriments). University ME students, as previously reported[12] during the senior project are exposed to project management methodologies and software, which evaluate overall design project cost information. Additionally, many students choose to take engineering economy as a course elective providing the framework for developing project income statements and cash flows to allow analysis of longer term project profitability under the influences of interest and inflation rates.

It is expected that global concerns can be accommodated through government and political considerations made by our students. Envisioning off-shore manufacture of the design might indeed stimulate this thought processes.

Conclusion
A method for the assessment of soft skills using engineering courses has been demonstrated. Specifically, the soft skills more difficult to evaluate including, lifelong learning competencies, communication, professional and ethical obligations, and the impact of engineering solutions have successfully been assessed with rubrics that have been presented. The ability to control course content and collect data solely through the use of engineering courses, allows the department to be self-reliant when assessing these skills. Further data collection and refinement of rubrics and assessment processes in alignment with course content enhancements, will lead to improved student learning and outcomes.

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