AC 2008-1041: USING PERFORMANCE REVIEWS IN CAPSTONE DESIGN COURSES FOR DEVELOPMENT AND ASSESSMENT OF PROFESSIONAL SKILLS

Greg Kremer, Ohio University-Athens

Dr. Kremer is an Associate Professor and Chair of the Mechanical Engineering Department at Ohio University. He teaches in the Mechanical Design area and has primary responsibility for the Capstone Design Experience. His main research interests are Energy and the Environment, especially as related to vehicle systems, and engineering education, especially related to integrated learning and professional skills. Dr. Kremer received his B.S. degree in Mechanical Engineering from Rose-Hulman Institute of Technology in 1989, his Ph.D. degree in Mechanical Engineering from the University of Cincinnati in 1998, and has five years of experience as a Mechanical Design Engineer at General Electric Aircraft Engines.

David Burnette, Ohio University

David Burnette was both an undergraduate student who participated in the OU ME Sr. capstone design project, and an OU ME graduate student who helped compile the student comments and complete the literature search for this study. He is currently an employee of the Bettis Atomic Power Laboratory.

USING PERFORMANCE REVIEWS IN CAPSTONE DESIGN COURSES FOR DEVELOPMENT AND ASSESSMENT OF PROFESSIONAL SKILLS

Introduction

In addition to completing a challenging technical curriculum, engineering graduates must demonstrate teamwork, communication, and other professional skills including professional and ethical responsibility, life-long learning, and understanding the impact of engineering solutions in a global and societal context. Unless these outcomes are integrated into students' conceptions of being a "successful engineer" (getting a job and advancing their career), they will be under-valued and under-developed. This project demonstrates the use of industry-modeled 360° performance reviews in a team-based capstone project to link professional skills with an integral "engineering identity" to enhance how students value and develop professional skills. An important component of this work is the development of a taxonomy of professional skills outcomes for mechanical engineers that are understandable to undergraduate engineering students and that are linked to the ABET professional skills outcomes. The study found that by framing the creation of a taxonomy of professional skills as a learning process, students gained an appreciation for the importance of the "professional skills" and a sufficient ability to identify what those "professional skills" look like in practice. Also, the integration of student-defined professional skills and subsequent discussion within a senior capstone course resulted in a relatively complete and mature list of skills and descriptions of performance levels that strongly matches expectations from industry. Additionally, involving students in the creation and implementation of the taxonomy of professional skills gives them ownership in the process and ensures they will understand them and be able to rate themselves and their teammates with respect to the professional skills. Several years of experience with the performance review methodology indicates that students can develop a thorough and meaningful list of professional skills and demonstrate an appreciation of the importance of professional skills, an ability to self evaluate relative to an individual area for improvement, and an ability to develop and complete a performance improvement plan for a specific professional skill. We propose that this is an authentic way to demonstrate achievement of the ABET professional skills outcomes.

Literature Search

Traditional methods of educating engineers have come under considerable criticism in the past two decades. Studies have found shortcomings in what was once the standard engineering curriculum. In 1994, a report released by the American Society for Engineering Education (ASEE) explained that, in addition to engineering fundamentals, an "understanding of the societal context of engineering" should be taught to students[1]. Explaining the role of engineering as an "integral process of societal change" had been put forward previously in a paper that encouraged educators to create an atmosphere that would allow students to "accept responsibility for civilization's progress"[2]. The following year the National Science Foundation (NSF) pleaded for the introduction of courses that would address social or political concerns as well as legal and ethical issues in engineering[3].

Later studies and resulting discussion eventually led ABET to revise its accreditation criteria in 1996. The criteria had previously focused on technical skills needed in the sciences. In addition to being more open-ended, the new criteria (Engineering Criteria 2000) put forth what are now called "professional skills" that include knowledge of contemporary issues and ethical responsibilities, a respect for life-long learning, and other skills relating to effective communication and the ability to function in multi-disciplinary teams[4]. Translation of EC2000 has generally been that professional skills are needed in addition to technical abilities due to the complex factors affecting decisions that engineers make and because of the different groups within which they work. Communication, leadership, and teamwork skills have been the subject of much engineering education research since then.

Although the ABET outcomes relating to these skills are very vague, some authors have attempted to define them[5]. In a study published in 2002, Lewis and Bonollo attempted to identify important professional skills by reviewing open-ended written evaluations of student work by 66 professional supervisors of senior design clinic projects. From 359 characterizable comments in the 66 evaluations they identified five professional skills that the supervisors valued highly in the student performance: negotiation with clients, problem solving, acceptance of responsibility for outcomes (professional behavior), interpersonal skills, and project management[6].

In a thorough summary of work done to develop and demonstrate professional skills, Shuman et al. argued that because of globalization and other issues, the professional skills are becoming increasingly more important and that "mastery of these professional skills combined with an ability to innovate will add sufficient value to U.S. engineering graduates so that price does not become the primary determinant in who is hired in the global marketplace[7]." They go on to identify methods for how the professional skills can be taught, breaking down the identified skills into "process skills" and "awareness skills." On the topic of assessment, Shuman et al. conclude that assessing professional skills is challenging and time consuming. They give a few examples of professional skills being assessed, but they do not report the effectiveness of the skill development activities and they admit that additional work needs to be done[7]. In terms of methods, they claim that "portfolios, along with performance appraisals and behavioral observations, offer the most comprehensive information for measuring many outcomes and are conducive to evaluating professional skills[7]." They also claim that "a performance appraisal is suitable for measuring such behaviorally based skills as evaluating an ethical dilemma or working on teams[7]."

Assessing communication, teamwork and ethics within a senior capstone is becoming fairly common, but there is still much confusion reported regarding the overall professional skills outcomes and how to assess them[8]. Although academia and industry have both pointed out the shortcomings in the old criteria, there has been little reported evidence as to what skills students themselves value or believe to be of value in industry. A survey conducted by Penn State University was undertaken which polled recent graduates and new undergraduates[9]. However, the categories rated by these groups were part of an existing survey. Specifically, there have been no studies on using industry-modeled peer reviews to educate students on the professional skills, nor has there been an investigation, to our knowledge, of how student-led assessments might affect the educational experience in an engineering curriculum.

Developing and Assessing Professional Skills

The study involved students participating in a year-long senior capstone design course. Typical class size is 50 students. Most are traditional students, and nearly 50% have some co-op or internship experience. Students are assigned to 8-person teams, selected to be diverse in skills, personality types, learning styles, and natural team roles. Teams go through some team building activities and are required to develop and use tools for effective teams such as team operating procedures and action item lists. The teams are given a common but general needs statement, and each of the 6 teams must identify a customer or market, refine the needs statement based on customer input, develop target specifications and a feasible conceptual design that meets them, refine the design using design methods (value engineering, design for safety, design for manufacturing and assembly, failure modes and effects analysis, etc.), build and test a prototype, and develop a production plan. Teams are encouraged to form collaborative learning groups (2-3 members) that take responsibility for learning how to apply certain design methods or use project management tools, and task groups (2-6 members) which are formed and reformed as needed to complete specific project tasks. The goal of the class is to help students make the transition from student behavior (responding to what the instructor asks for) to professional behavior (responding to open-ended problems, dealing with uncertainty, and making good decisions based on informed engineering judgment).

Although communication skills and teamwork skills have always been strongly emphasized in our class and in most capstone experiences, other professional skills traditionally receive less attention. In 2005, as part of a project with the Carnegie Academy for the Scholarship of Teaching and Learning, we began an increased emphasis on developing and assessing other professional skills. To motivate students to develop these skills, we collected examples of performance reviews from our industrial advisory board and from other sources, showing students that the methods used to evaluate engineers in industry actually include a strong emphasis on professional skills. Then to establish the criteria for our performance review, students were asked to create a list of skills that would be valuable for engineers, based on their ongoing capstone design project experience. They were told that the categories that resulted from their suggestions would be the ones they would use to rate themselves and their peers. During the first year, there was an attempt to base the taxonomy of skills on a developmental framework, with the students suggesting levels of behavior for skills they thought were important. A selection of student input is shown in Table 1.

Based on end of the year student surveys, 35 out of 40 respondents indicated that their understanding of what it means to be a good engineer changed over the course of the project, and 34 of 43 agreed that it was important that each year the students should be engaged in either modifying or creating a new skills list since the creation of it was a significant part of the learning experience.

In addition to their participation in the creation of the table, students were required to use it to rate themselves and their peers, and to give examples or describe experiences that demonstrate use of several of the professional skills. Assessment of the student responses showed that 9 out of 48 students had marginal quality examples, 26 out of 48 were acceptable, and 13 of 49 were above expectations. Finally, all students met with the professor for a face-to-face performance

review to discuss differences between their self rating and how their peers rated them, and to discuss a development plan for one skill area that they needed to improve. A follow up reflection report was later submitted on the skills development project. Based on an overall assessment that considered the students' ability to describe examples that demonstrate professional skills, to provide an honest rating of themselves and their peers relative to professional skills, and the ability to design and implement a plan to improve performance in a professional skill, 75% of the students met the outcome. This number would have been even higher if not for senioritis – several of the activities were completed late in the Spring quarter.

Table 1: Levels of Development (correlated with Bloom's affective levels), and what the characteristics look like in practice for the various levels

Skill	Ignorance (Receiving)	Awareness (Responding)	Importance (Valuing / Organizing)	Embodiment (Internalizing)
Attitude and character	Doesn't want to do any work & doesn't care about others; always looks at the negative side of things. Selfish motives, motivated by external factors ($, boss) and personal gain. Only acts when prodded.	Sometimes is optimistic about doing work but would usually prefer to avoid it. Usually takes on responsibilities only when asked to. Expects others to make no mistakes.	Usually is optimistic about doing work and takes on tasks willingly, but sometimes is stressed and wants to avoid extra work. Is not unrealistic in expectations of others. Often motivated internally and for the common good.	Thrilled to face a challenge & do work; always in a good mood and looks at the positive side of things. Tackles tasks wholeheartedly and works diligently to see the task completed fully. Acts selflessly for the benefit of others.

Although the overall process worked well the first year, the developmental model proved inappropriate due to issues of situational dependence (many people behave differently depending on extenuating circumstances, so it is hard to define what level they are at), the unlikelihood that significant development will occur in a period of 9 months, and the difficulty of proving professional development. We found that it was much better to have performance levels for the skills referenced to "professional expectations" than developmental levels. So the next year, students were again provided with a blank spreadsheet with one example (interpersonal communication), but this time they were asked to identify important professional skills and for those skills provide descriptions of behaviors that would meet industry expectations, fall below those expectations, and exceed those expectations. A Teaching Assistant compiled the student input, merged skills that seemed the same, categorized the skills, and produced the rating form shown in Table 2. All of the skills listed in the survey were provided by students. Proposed skills were only omitted from the final table if only one student proposed the skill or if the description of the skill clearly did not meet the level to which it was attributed. For example, if a student listed integrity as a desired skill and described the "meets expectations" level as "rarely

being dishonest about sources" then that piece of data would be omitted since plagiarism is would never be accepted in industry.

After the peer assessment was created categories and descriptions were returned to students for further review and refinement. Feedback was also requested from a board of eight industrial advisors, who were unanimously impressed with the sophistication of the student responses. Since most employee evaluations are very specific to an industry even in the case of peer evaluations, the assessment created by the students was more comprehensive than most industrial evaluation forms. Finally, each design team was asked to discuss and come to a consensus rating for the value of each skill in the final list using a scale of 1 to 5, with five being the most valuable. The average of the ratings for all teams can be found in the final column in Table 2. Problem Solving, participation, and integrity were the three top-rated skills, while influence, business awareness, and emotional intelligence were judged to be the least important in the context of this design experience.

Once the survey was completed, students used this to evaluate themselves and their group members on the listed skills. Students could rate each other as unacceptable, meeting expectations, or as being a true professional. A number of 1 through 9, three marks within each level of scoring, could be given as a score in hopes that this would prevent everyone from receiving similar marks. The results were collected and tallied near the end of the second quarter of the course. As in the previous year, the instructor met with each student individually to discuss the results of the peer reviews and to identify an area for improvement. Every student was asked to come up with a list of actions to help improve their performance in this area for the remainder of the capstone course, after which they discussed their progress with the instructor.

Table 2: Taxonomy of professional skills for Mechanical Engineers in a product development project, referenced to student conceptions of the expectations of the profession.

	Unacceptable	**Meets Expectations**	**True Professional**	**Average Weight**
Teamwork	1 2 3	4 5 6	7 8 9	
Interpersonal Communication	Sticks to opinions without compromise, overbearing, unable to listen, pushes ideas	Works well with others, respects opinions, and is open to compromise	Encourages and welcomes the opinions of everyone	4.18
Attitude	Negative or cynical attitude, gives up	Tries to stay positive, looks on the bright side	Maintains positive and optimistic attitude, inspires other to do so	4.12
Emotional Intelligence	Oblivious to the emotional state of others or doesn't care, doesn't realize impact on others	Understands individuals and avoids offending directly or indirectly	Sensitive to the feelings of others and understands his/her own impact on others	2.68
Participation	Very little participation in meetings, doesn't offer ideas or opinions, doesn't complete work on time	Offers opinions and feedback, finishes assigned work on time	Leads conversations, gives and welcomes ideas, requests additional work	4.68
Dependability / Punctuality	Frequently late, forgetful, lets others finish work, inconsistent performance	Usually on time, completes tasks assigned	Very consistent, never late, gets there early, finishes work and helps others	4.44

Table 2: Continued

	Unacceptable			Meets Expectations			True Professional			Average Weight
Project Management	1	2	3	4	5	6	7	8	9	
Prioritization	Poor or complete inability to prioritize tasks for best overall success of company			Understands the need for prioritization and willing to identify and act accordingly			Good understanding of company needs and time issues resulting in excellent prioritization			3.96
Planning	Poor or no planning often leads to being unprepared, lost time, or missed deadlines			Prepared in most cases, plans to meet deadlines, good feel for progress of project			Thorough yet adaptive planning, always prepared, vision of future			4.14
Organization	Disorganization leads to lost time, incomplete work, and missed deadlines			Maintains records and files in case needed			Keeps excellent and reliable records that can be easily understood by others			3.84
Resource Allocation	Unable to effectively distribute resources to designated priorities			Good feel for distribution of resources based on given priority			Very good execution of resource distribution based on priorities and available assets			3.46

	Unacceptable			Meets Expectations			True Professional			Average Weight
Character Attributes	1	2	3	4	5	6	7	8	9	
Honesty & Integrity	Willing to misrepresent the value or source of data,bends rules, does not bring up mistakes if it reflects poorly on him/her, exaggerates			Always honest, follows rules, admits mistakes, never changes dates / data			Is an example of integrity, pushes others to uphold integrity, admits mistakes and is always honest regardless of affect on bottom line			4.56
Work Ethic	Must be pushed to get work done, no drive, does not show up or complete tasks, lets others do their work			Desire to complete all assigned work in a satisfactory way, desire to improve performance, consistent and accountable			Goes above and beyond assigned tasks, quality driven, ambitious, wants to move beyond assigned roles			4.32
Loyalty to Company or Team	Unwilling to do additional work when needed, quits and switches jobs often			Willing to stay over or come in early on occasion to meet deadlines			Strong dedication to the work, puts in extra time to better performance of self and company, enjoys work			3.26
Personal Development	Does not see a reason to learn new skills, knows everything and has no interest, unable to learn new skills			Stays updated on technology and processes relevant for job to improve performance, asks questions, trainable			Seeks out new ideas and technologies to improve self and others, embraces life-long learning, easily taught and teaches others well			2.82
Business Awareness	Not aware or doesn't care about company vision or individual impact / role in company			Understands the operations of the business and the company vision			Very familiar with and dedicated to company operations and vision, works hard in best interest of both			2.68
Accountability	Does not accept responsibility for work or failure, does not identify individual work			Takes responsibility for his / her own work and clearly identifies it			Identifies and accepts full responsibility for work consistently even when outside of standard roles			4.42

Table 2: Continued

	Unacceptable	Meets Expectations	True Professional	Average Weight
Personal Abilities	1 2 3	4 5 6	7 8 9	
Technical Ability	Poor engineering skills or low aptitude, unable to perform or understand required tasks	Firm grasp on skills and fundamentals such that can understand new problems and perform/learn skills	Extremely knowledgeable, known reference to others, capable of handling advanced problems	3.82
Problem Solving	Rarely identifies issues or comes up with unique or independent solutions, does not know how to approach problems or apply engineering skills to do so	Can apply engineering tools and principles to identify and solve problems consistently	Consistently identifies, approaches, and solves problems in innovative ways	4.76
Public Speaking	Fear of public speaking, unable, boring presentations or speeches	Willing to present / speak to groups, presents clearly and concisely, understandable material	Eager to explain to groups, produces interesting, engaging speeches / presentations	2.66
Technical Communication	Unable to communicate technical information in an understandable way, poor writing and verbal skills	Able to communicate technical information in verbal and written form	Can explain technical issues to non-technical audiences in written or verbal form	3.42
Creativity	Doesn't move away from status quo, not open to new ideas	Open to new ideas and methods of improvement	Strives for new ideas, thinks outside of the box	3.46

	Unacceptable	Meets Expectations	True Professional	Average Weight
Leadership	1 2 3	4 5 6	7 8 9	
Vision	Has no vision of the future or does not project vision	Has vision and makes known for others to follow	Inspires others with vision, encourages shared vision and communicates it well	3.08
Influence	Leads through coercion, belittles, doesn't inspire, little influence	Able to influence others, can barter, sets example, persuasive	Influences by empowering, advises others, encouraging, very persuasive	2.58
Decisions & Management	Micromanages, does not listen to recommendations, bossy	Makes well informed decisions based upon feedback from followers	Seemingly doesn't lead, allows employees space to develop	4
Rewards	Selfish, issues blame and takes credit	Assumes responsibility for followers and distributes credit for success	Humble, passes out credit to followers, assumes blame for all mistakes under him/her	2.74
Attitude	Bossy, poor integrity, no attempt to motivate or encourage	Gets along well, good integrity, encourages employee	Always positive attitude, approachable, trusted, considerate of followers	3.87

The results for the second year of the study were very positive. The peer assessment form, which was constructed completely from student input, shows a very mature understanding of the value of professional skills and the expectations for each. While no single student had a comprehensive list of this nature, it has been proven that individual ideas and resulting discussion by students in a capstone course can result in the formation of a very sophisticated system of peer evaluations. Once again student achievement of the outcomes was assessed relative to the same criteria as used the first year, plus an assessment of their ability to explain the reason for the expectations of the profession, and their ability to compare examples of behaviors to the expectations of the profession. Nearly all students were judged to have achieved the outcome in the second year, with the few exceptions being due to not following through on their skill development plans. The increased rate of achieving the outcomes may have been due to the more organized approach, the fact that the switch to professional expectations made the process more authentic, or just the fact that the deliverables were completed earlier in the year before senioritis kicked in.

It is important to remember that since this study was conducted as part of a senior capstone group project, the valued skills listed may be indicative of those that would be more useful in a mechanical design group as opposed to other settings. This was certainly the case when existing industry reviews were examined. In fact, this may be preferred since removing any context when creating a survey may cause it to lose any value. However, the feedback from students did seem to encompass more than the typical problems seen in a ME senior design course and there was obviously some overlap between the categories which just couldn't be avoided. For this reason and also to provide a context for the student feedback, separate categories were created to house the related skills. This also helped the authors digest the results and summarize where students' concerns were.

The ratings for skills in the "teamwork" category were very much what would be expected of students. Participation was rated as the most important since everyone wants team members who will pull their weight, while emotional intelligence was rated the least valuable. The group nature of this course means that lectures were held regarding team building and teamwork, but it seems that engineering students, like many professional engineers, do not have a deep appreciation for emotional intelligence.

The "project management" category contains business skills that engineers must inevitably learn in order to work in a real life industry setting. Since this was a project-oriented course, feedback was expected to be directed into this category. There was no large difference in the ratings of the skills in this category, perhaps due to their similarities. However, these skills were the most common skills students listed when initially providing their skills lists.

The "character attributes" category got this name since the comments and skills provided therein are directed toward an individual rather than a group and relate to a person's personality rather than more standard skills. It was reassuring to see that students rated "honesty & integrity" the most important of this category. Since most of the students in this study have not worked as an engineer in industry full time, it is quite understandable why "business awareness" would be seen as the lowest priority. Furthermore, it would be very difficult to say that most engineers have an appreciation of their employer's current state of business.

Skills such as interpersonal communication and problem solving were part of the “personal abilities” category. For this group, “problem solving” was the most highly rated skill and “public speaking” had the lowest rating, even though formal and informal oral presentations are very frequent in the capstone course and comprise a significant portion of the grading. These ratings are most likely reflective of the fact that students tend to value project work (getting the design done) over communication (talking or writing about what was done). Students often comment in evaluations of the capstone design course that the communication requirements "get in the way" of their project work.

The ratings of the “leadership” category reflect the fact that despite selecting group leaders, the students within every group were all technically peers. Typical leadership qualities such as vision and the ability to influence received lower scores than managing style and attitude.

Conclusions

The study found that although not all individual mechanical engineering students have a comprehensive grasp of the “professional skills” that are valued in industry, the integration of student ideas and subsequent discussion within a senior capstone course did result in a skills list and descriptions that strongly matches expectations from industry. Since the ABET professional skills outcomes are somewhat vague and no professional organization has put forth a specific skill set for mechanical engineers, there is currently no comparison for the student-created taxonomy of skills, which appears to be the first of its kind published in engineering.

Although only a small part of this overall work, evaluating the student ratings of the importance of the skills revealed some student perspectives that can be used in the future when emphasizing the importance of professional skills to an engineer’s career. The ratings of the importance of the skills by the teams implies that mechanical engineering students see themselves as problem solvers who value honesty and integrity, which is the type of “engineering identity” we hope to achieve in our graduates. Another positive aspect of the capstone experience is reflected in student comments such as: “More than an engineering project, this class has been a journey of personal growth that I have not taken for granted.”

From a development perspective, involving students in the creation of the skills list that is used for their performance review forces them to reflect on what skills they think are valuable in a team context (as they work together to solve a complex engineering problem), and the 360 degree performance review format which asks for examples of how they and their team members have exhibited the professional skills in the context of their capstone project serves both as a development activity as well as an authentic assessment of their ability to judge a behavior relative to the expectations of the profession.

Although the importance of professional skills is well accepted among engineering educators, there appears to be a lack of authentic methods for developing and assessing any skills beyond communication and teamwork. We believe that the performance review approach, coupled with the assessment of students’ ability to describe example behaviors for numerous skill areas, compare them to the expectations of the profession, and develop and implement plans to improve

performance in a specific skill area, is an authentic way to develop and demonstrate achievement of the ABET professional skills outcomes.

Bibliography

1. Augustine, N., and Vest, C., *Engineering Education for a Changing World,* Joint Project by the Engineering Deans Council and the Corporate Roundtable of the American Society for Engineering Education, ASEE, 1994.
2. Bordogna, J.E., Fromm, and Ernst, E.W., *Engineering Education: Innovation through Integration*, Journal of Engineering Education v.82, No.1, 1993, pp.3-8.
3. National Science Foundation, *Restructuring Engineering Education: A Focus on Change*, Division of Undergraduate Education, Directorate for Education and Human Resources, NSF, 1995.
4. ABET, Criteria for Accrediting Programs, Baltimore, MD: Engineering Accreditation Commission, March 17, 2007.
5. Besterfield-Sacre, M.E., Shuman, L.J., Wolf, H., Atman, C.J., McGourty, J., Miller, R.L., Olds, B.M., Roger, G. "*Definsing the Outcomes: A Framework for EC2000*," IEEE Transactions on Engineering Education vol. 43, No. 2, 2000, pp.100-110.
6. Lewis, W.P. and Bonollo, E., *An analysis of professional skills in design: implications for education and research. Design Studies*, V23, 2002. pp. 385-406.
7. Shuman, L.J., Besterfield-Sacre, M.E., McGourty, J., "*The ABET "Professional Skills" – Can They Be Taught? Can They Be Assessed?"* Journal of Engineering Education, January 2005, pp.41-55.
8. McKenzie, L.J., Trevisan, M.S., Davis, D.C., Beyeerlein, S.W., "*Capstone Design Courses and Assessment: A National Study*," Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition
9. Barron, K.A., Pangborn, R.N., Lee, S.H., Litzinger, T.A., Wise, J.C., "*Educational Objectives and Expectations for Post-Graduation Achievement*" Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition