

AC 2008-2421: CAREER DEVELOPMENT AND PROFESSIONALISM WITHIN A BIOMEDICAL ENGINEERING CAPSTONE COURSE

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Career Development and Professionalism within a Biomedical Engineering Capstone Course

Abstract

Many facets of professionalism in addition to technical skills are critical for engineers as they seek to put their knowledge and problem-solving experience into action in the workforce. The so-called “professional skills” necessary for productive career development (e.g. effective written and oral communication, networking, etc.) are especially important in biomedical engineering (BME) due to the rapidly evolving nature of the field and the diversity of students attracted to BME – and the correspondingly broad range of careers that they choose to pursue, including biomedical and biotech industries, academic research, intellectual property, FDA regulation, consulting, finance, and other professional tracks. To address the need for undergraduates to possess adequate non-technical skills prior to graduation, BME curricula typically use capstone courses as vehicles for teaching professionalism. In the BME Capstone course at the University of Virginia, we have instituted several mechanisms for instilling a wide array of non-technical professional skills in BME majors. An emphasis on career development begins at the outset of the course with a formal project selection process that features a BME Capstone “Project Fair,” which is similar to a job fair where the students submit resumes and interview with potential advisors and then submit formal cover letters to apply for their top-ranked projects. Interactive workshops and lectures throughout the year cover topics such as interviewing, negotiations, giving constructive feedback, and effective leadership. The Capstone course also employs periodic corporate-style progress reports, “Solutions Workshop” small-group discussion sections that require students to succinctly summarize their project and respond to in-depth questioning, and individual accountability meetings. Preliminary assessment of these enhancements to our BME Capstone course has revealed that students, on average, have greatly improved in their ability to: verbally communicate the details of their projects concisely; convey the overarching problem that motivates their work; speak confidently about what they have accomplished and where their projects are headed; recognize when they require additional expertise and guidance; understand better how to use their existing networks and build on these networks to find such additional expertise when necessary; and consistently communicate with their advisors and collaborators in a timely and professional manner. The initial successes observed after applying these methods in our BME Capstone program indicate that a strong emphasis on a broad array of non-technical skills enhances student professionalism, thus more effectively empowering graduates to embark upon successful careers.

Introduction

Almost invariably, engineering curricula heavily emphasize the development of technical skills: knowledge of mathematics and the sciences, problem solving, engineering practice, experimentation, and design. However, non-technical skills – the so-called professional skills – are increasingly seen as essential to the complete education of a modern engineer, thus leading to these skills’ explicit delineation in ABET Criterion 3, Program Outcomes d, f, g, h, i, and j.¹ However, there has been considerable debate as to how such skills (sometimes less favorably referred to as “soft skills”) are most effectively taught and assessed.²

A national survey of capstone courses in multiple engineering departments showed a clear overall trend in the increasing emphasis on professional skills within the capstone design course,³ and 95% of engineering capstone programs surveyed in a separate study stated that a goal of their capstone project was to empower students to communicate effectively.⁴ There is less emphasis on assessing some of the professional skills, however; for example, life-long learning was assessed in only 37% of capstone programs nationwide.⁴

Process oriented skills relating to interdisciplinary communication have been widely studied,² particularly with respect to team building and team dynamics in engineering design.⁵ The field of biomedical engineering (BME) is, by its very nature, a broad, highly interdisciplinary field.^{6,7} In fact, we view BME as unique in the challenges posed to communication given the wide array of clients, especially physicians and clinicians. The ability to work well with collaborators (not just immediate members of a design team) is essential to success in BME, whether in industry, the clinic, or academia. Moreover, specialized knowledge and skills are needed for communication with collaborators in the various sectors pertinent to BME.⁸

The integration of professional skills into a BME curriculum at a holistic level (not just “inoculated” into a specific course) has been described previously in the implementation of problem-based learning throughout a curriculum.⁹ However, there has been little publication of such methods for teaching and assessing professional skills within a BME capstone course. Current textbooks in BME design typically focus on the technical aspects of the design process as it relates to biotechnology, medicine, FDA regulation, and healthcare.¹⁰ However, aside from limited discussion of oral presentation, record-keeping, technical report writing, and general communication, such texts do not cover professional skills in depth.

Implementation within a BME Capstone program

The Biomedical Engineering Capstone Design sequence at the University of Virginia is a yearlong (two semester) course taken in the fourth and final year of study in the major. The course includes two 50-minute lectures/discussions per week, and the students are expected to spend at least 10-12 hours per week outside of class working on their projects. Students are allowed to work either individually or as part of a team of their classmates; however, all students recognize that they are part of a broader team (i.e. not just consisting of their classmates) that includes an advisor and also collaborators from multiple departments. Team size ranges from 1 student (e.g. a Capstone student working with a cardiologist and a mechanical engineer, and also with a 3rd-year undergraduate in BME who is not taking Capstone) to as many as 6 students. The average team size has been ~2 Capstone students. The class sizes the past two years were 75 students (2006-2007) and 64 students (2007-2008). The methods described in this manuscript for enhancing professional skills were implemented for the 2007-2008 academic year, thus forming the basis of comparison for assessment.

The professional skills mentioned previously are implemented in our Capstone course in numerous ways (Table 1), several of which are highlighted in the sections that follow. By way of background, students in our program have covered many professional skills prior to taking Capstone. In the second year, they study team dynamics, personality types, and interpersonal

communication in detail, including formal assessments of and reflections on their Myers-Briggs Type Indicator (MBTI) and Fundamental Interpersonal Relations Orientation-Behavior (FIRO-B) results. Additionally, they participate in a discussion series with readings relevant to the field, often on contentious topics (embryonic stem cell research, the role of design in biomedical research, biomedical ethics, etc.). In other classes in the third year of study in our curriculum, students focus on concise, clear technical writing, as well as oral presentations. Other required courses within our Engineering School emphasize the global, societal, and ethical impact of engineering endeavors.

The sections that follow describe the methods we have implemented in our Biomedical Engineering Capstone Course sequence to address the need for additional professional skills development in our undergraduates. The overarching aims of these methods are not necessarily unique to our program, but they nonetheless constitute what we believe to be an effective means of developing professional skills in our senior Capstone students.

Project Selection Process: Maximizing Student Buy-In from the Outset

The BME Capstone Program at the University of Virginia affords students considerable flexibility in how they are assigned particular projects. In our experience, overall student performance and effort correlate more or less directly with their enthusiasm and buy-in for their respective projects. Accordingly, we have devised a system of project assignment such that students feel both ownership of and accountability for their projects from the start of the Capstone course.

In the months prior to the start of class, the instructors compile a booklet of potential projects (subject to instructor approval) solicited from clinicians, faculty, and entrepreneurs from within the BME department, the nursing school, the hospital, and local companies. These potential clients submit a Project Description that includes each client's contact information, department (or company), the project type, keywords, a one-paragraph background summary, brief project goals, motivation, techniques to learn and/or develop, the ideal team size, and career applicability (e.g. medical school, the medical device industry, nursing, etc.). At the start of the academic year, this booklet is distributed to the Capstone students for their consideration.

Approximately one week after the project booklet is handed out, we hold a "BME Capstone Project Fair," where all the potential clients and the students gather to interview one another for the various projects. This event is run very much like a job fair, where the clients set up booths (often with props, slides, computers, or other material with which to communicate their problems of interest most effectively), and the students, resumes in hand, mingle from booth to booth and discuss the projects with the potential clients. In this event, each party is evaluating the other: the students are determining whether or not they are interested in a given project, and the clients in whether or not they want to "hire" a given student, given how the student came across (and given the strength of the resume).

Students also have the option to submit projects of their own devising, provided they identify a willing client. However, these student-submitted projects are subject to instructor approval to ensure that the topic is suitable for a BME Capstone project. Our criteria are four-fold: 1)

Projects must have relevance to the biomedical field; 2) Projects must be novel; 3) Projects must involve the design process and be problem-focused, not purely hypothesis-driven (i.e. a client cannot simply assign a student to perform a set of pre-specified experiments, thus amounting to a research technician project rather than a true design project); and 4) Projects must involve continuous work over both the fall and spring semesters (i.e. students cannot solely submit work that they performed previously, e.g. during a summer internship). These four criteria also apply to the projects that the instructors solicit from potential clients (see preceding paragraph).

One week after the Project Fair, students submit at least two cover letters applying for their top two project choices. These letters must describe the student's qualifications for the particular projects of interest, and they must justify how the skills learned in tackling each problem will fit with their overarching career goals. Having the students consider the long-term career benefits of their projects helps them to appreciate the importance of Capstone to their educational development, thus increasing their buy-in to the course as a whole. Those students who submit their own project for approval must still write two cover letters: one for their own project, and the other for their top choice among the available projects in the booklet. Additionally, each student submits a project preference form, on which they rate every available project from 1 to 4 (where 1 = extremely interested, 2 = very interested, 3 = moderately interested, 4 = not interested in project). Potential clients also submit their preferences for particular students based on their interaction at the Project Fair. The Capstone instructors then act as brokers to optimally allocate each student to their projects. This past fall, every student in our Capstone class was assigned his/her first or second choice of project.

Solutions Workshops

Once a week the Capstone instructors and teaching assistants (TAs) hold "Solutions Workshops", which are hour-long discussion sessions where four to five Capstone Teams are asked, one at a time, to orally summarize (in the span of approximately ten minutes) the progress they have made to date on their Capstone projects, any hurdles or problems that have arisen, any recent successes that the team has experienced, any resources that are required at that juncture, and work plans for the upcoming weeks. After each team presents this information, the project is open for discussion by the Capstone students on other teams, the instructors, and the TAs. The role of the instructors and TAs is to help the students focus their design endeavors, communicate their ideas more succinctly and effectively, and defend their decisions. In this role, the instructors and TAs act much like high-level project advisors or managers, who may be less familiar with the details of the project, but expect the (student) team to be intimately familiar with the project and its needs at a given time.

Not only does this experience offer a valuable opportunity for the presenting teams to practice giving a concise summary of the key project details in the time window of a few minutes, but it also allows the teams in the audience to critically analyze and assess the other teams' projects and provide useful, collegial feedback. Therefore, the Solutions Workshops allow the students to practice professional oral communication skills that are frequently utilized by engineers in the workplace when project teams interact to troubleshoot problems and critically assess progress and future avenues of pursuit.

Pro-Tips of the Week

Starting in late September, the Capstone instructors send weekly e-mails to the entire class that summarize important tips for professional communication and conduct. We term these e-mails “Pro-Tips,” and the students are asked to read, retain, and employ the information and suggestions contained in them. The Pro-Tips cover a range of topics, including:

- how to prepare for and conduct oneself in a meeting with a supervisor or advisor,
- how to manage a professional relationship with a supervisor or advisor via regular and punctual e-mail correspondence,
- how to organize and synthesize a personal statement for graduate school or medical school,
- how to ask questions when one is trying to learn about a project, and
- how to establish ownership of a project, demonstrate leadership on a team, and project self-confidence when speaking with a superior or advisor.

Pro-Tips average 3-4 paragraphs in length, and frequently include example situational scenarios that the student may have experienced (or may be about to experience) in the course of their Capstone project or examples of how one can conduct oneself in a professional manner, given a specific set of circumstances. For example, the Pro-Tip regarding the sending of e-mails to supervisors or advisors (bullet #1 above) suggests the following responses, given a specific situation: “If your advisor e-mails you with information regarding your project, about scheduling an upcoming meeting, with a question, suggestion or request, you should immediately respond to that e-mail to signify that you have received it. A suitable response may include, ‘I am working on getting you an answer, but I need to consult with my teammate before I can give you a firm response. You can expect to hear from me by this Wednesday.’” We often find that students at this stage in their training learn professional behavior by patterning them according to behaviors that they have observed being exhibited by others. By providing students with these situational scenarios and suggesting an appropriate professional behavior (or examples thereof), students can begin to learn what professional behaviors are acceptable and expected in the work place.

The delivery of these Pro-Tip e-mails temporally coincides with experiences that the students have in the early- and mid-stage of their Capstone projects: when they are first establishing a relationship with the advisor or mentor, when they are conducting prior art searches and literature searches and attempting to familiarize themselves with the background of the project, when they are engaged in the conceptual planning stages, and when they are taking over ownership and becoming the project “experts.” We assess the students’ retention of the Pro-Tip information by administering a pop quiz in the middle of the semester. At that time, the students are also polled for further ideas they might have for Pro-Tips, based on any hurdles or deficiencies that they have experienced in professional interactions with their own team, with their advisor, or outside of our course.

Lectures and Workshops Covering Additional Professional Skills

In addition to the aspects of the Capstone course described above, we include several guest lectures and interactive workshops covering a range of topics pertaining to professionalism.

These topics are by no means unique to our program, and so we only treat them briefly here. These topics include: 1) *Negotiations workshops*: Students are assigned case studies of either side of a negotiation. They then break up into groups (the two parties, along with a neutral third observer) to attempt to achieve their aims going into the negotiations. This exercise leads into an in-depth discussion on best practices in the art of negotiation. 2) *Business and research ethics*: Discussion of case studies relevant to biomedical engineering ethics problems are led by guest lecturers with expertise in these topics. 3) *Investing*: While not necessarily a “professional skill” as such skills are normally defined, we have included a guest lecture on financial management, investing, and retirement planning, since a majority of our students expressed a strong desire for a primer in this topic. 4) *Leadership and entrepreneurship*: Students are led in discussions of case studies in both of these topics and, in the case of leadership, are asked to reflect on their own experiences with teamwork in our program.

Table 1. Summary of professional skills covered in the U.Va. BME Capstone sequence.

Skills	Implementation	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Job Search	Resume Workshop	■							
	Cover Letter Assignment	■							
	Alumni Career Panel						■		
Interviewing	Interviewing In-class Activity	■							
	BME Capstone Project Fair	■							
Oral Progress Report	Solutions Workshops		■	■	■				
	Mid-Year Oral Reports				■				■
Formal Oral Presentation	BME Capstone Symposium								■
Written Proposal	Mid-Year Proposal		■	■	■				
Written Progress Report	Progress Report Assignments(3)						■	■	■
Written Final Report	Final BME Capstone Report								■
Business Ethics	Case Study In-class Activity						■		
Research Ethics	Case Study In-class Activity							■	
Private Funding Opportunities	Guest Lecture						■		
Public Funding Opportunities	Lecture								■
Investing	Guest Lecture							■	
Negotiating	Guest Lecture and In-class Activity							■	
Leadership	Guest Lecture and In-class Activity							■	
Protecting your IP	Guest Lecture and Provisional Patent Disclosure								■
Entrepreneurship	Guest Lectures						■		■

Assessment

Assessment of the professional development methods implemented in the BME Capstone course sequence at the University of Virginia was conducted using oral and written communication from students, anonymous course evaluations, and client and instructor assessment of students. Additionally, summative assessment of student performance in distinct professional skills categories was conducted after the fall semester of Capstone for the past two years. In the fall

2006 offering of Capstone, there was no Project Fair, limited career development workshops (e.g. no interviewing workshop), no Solutions Workshops, and no Pro-Tips. Each of these methods was implemented for the first time in fall 2007 specifically to address perceived shortcomings in the professional skills of many of the students the previous year. Thus, while no longitudinal data are available to fully elucidate the effectiveness of these measures, we can indirectly assess these techniques by comparing the performance of the two classes (consisting of 75 students in 2006, and 64 students in 2007).

Student and client feedback on the project selection process and the Project Fair in 2007 (collected verbally and in the course evaluations) was very positive, on the whole. The potential clients greatly appreciated the opportunity to both recruit and evaluate students, and the students felt that the Fair provided them with a good means of comparing the available topics and collecting sufficient information to make an informed decision. This informed decision, in turn, led to greater buy-in to their projects, thus fulfilling one of the major goals of the Fair.

The Solutions Workshops were also assessed verbally and via end-of-semester evaluations. The student response to these was generally positive, with a number of students telling an instructor that he/she appreciated the opportunity to listen to us discuss and brainstorm other students' projects (not simply their own). Many of them noted that issues often arose that were common to multiple design endeavors, and thus they benefited from hearing these issues discussed for projects other than theirs. One student wrote in an evaluation: "Overall I think this course was taught as best as it could be considering the actual meat of the course occurs outside of the class time. The [Solutions Workshops] were effective and allowed us to use the class time to do our projects." The weekly "Pro-tips" received similarly positive responses from students (e.g. one evaluation reads "...the weekly pro tips were very informative").

While student evaluations are not necessarily indicative of their learning of professional skills, our goals in implementing the above methods were not only to better prepare the students, but also to enhance their overall experience in the course. Student evaluations of the course are therefore useful in measuring their response to the changes enacted, particularly in each fall semester (when most of the changes were applied). In general, the numerical course evaluations for the fall semester of the course sequence in 2007 increased relative to 2006 (when these professional skills were not emphasized using the described methods). On a five-point Likert scale, the students' response to "I learned a great deal from this course" increased by 0.53 (from 3.44 to 3.97, Wilcoxon $p = 0.002$), and the response to "The course material was well organized and developed" increased by 0.41 (from 3.84 To 4.25, Wilcoxon $p = 0.002$). However, the students' overall impression of the worth of the course did not significantly improve from 2006 to 2007 (Wilcoxon $p = 0.117$), based on their response to "Overall, this was a worthwhile course" (which increased by 0.26, from 3.69 to 3.95).

In addition to feedback and evaluations from students, the Capstone instructors assigned scores for "communication" (reflecting ABET outcome 3.g) and "resourcefulness" (indicative of outcome 3.i) to each student in both years of the course at the end of the fall semester. The *communication* score was based on client feedback (with respect to the student team's level of professional communication with the client) and also on each student's overall ability to communicate his/her progress throughout the semester (both in individual meetings and in the

final presentation). The *resourcefulness* score was based on the client's and the instructor's assessment of each student's engagement, ability to proactively seek out and communicate with external collaborators when necessary, and their ability to learn new skills without significant guidance, as measured at the end of the fall semester of each year (2006 and 2007). These categories were rated on a scale of 1 (lowest) to 5 (highest). We observed a statistically significant (Wilcoxon $p < 0.05$) increase in the communication average from 2006 to 2007 (3.76 to 4.14, $p = 0.032$), but there was not a significant increase in the resourcefulness score (3.53 to 3.73, $p = 0.256$). Additionally, summing these two metrics generated a composite "professionalism" score. Students who scored below 6 (out of 10) on this combined metric were considered not to meet the objective of exhibiting sufficient professional skills by the end of the fall semester. In 2006, 79% of 75 students met the objective, and in 2007 after the implementation of the methods described in this paper, 91% (of 64 students) met this objective. However, the mean increase in the composite score (7.27 to 7.89) was not statistically significant ($p = 0.091$).

Conclusion

Overall, the methods described for enhancing professional skills (e.g. communication skills, lifelong learning, ability to function on multidisciplinary teams, etc.) within a biomedical engineering Capstone course appear to be effective based on anecdotal as well as preliminary assessment data. Summative assessment of student performance in these categories showed improvement after the implementation of methods such as the Capstone Project Fair, the interview workshop, the Solutions Workshops, and the weekly Pro-Tip e-mails. Additionally, these methods were well received by students and clients as reported verbally and in formal course evaluations. However, to fully assess the efficacy of the described techniques for actually improving students' performance outcomes in the ABET professional skills categories, a longitudinal study using the same group of students will have to be performed. Accordingly, we are planning to conduct such a study by evaluating undergraduates in our program from the second through the fourth year of study. Additionally, more rigorous quantitative metrics for the professional skills need to be developed, as the current *communication* and *resourcefulness* metrics are somewhat subjective. Taken together, however, the preliminary results presented in this paper indicate that the methods described exhibit promise for better achieving these very important ABET outcomes within a biomedical engineering Capstone course.

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