

2007: CHALLENGES IN MENTORING INDIVIDUALS IN BIOMEDICAL ENGINEERING TEAM DESIGN PROJECTS

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Challenges in Mentoring Individuals in Biomedical Engineering Team Design Projects

Abstract

The undergraduate curriculum in biomedical engineering at Purdue University allows students to practice design and teamwork skills each semester, culminating in the capstone design experience in the senior year. The capstone course is a unique opportunity for students to experience real-world projects and for instructors to carry out assessment and mentoring practices that prepare students for professional practice. Our approach is unique, in that assessment and mentoring are directly related to one another. Assessment is built into the course through measurement of student performance using detailed rubrics. Mentoring occurs in many formats: detailed critiques of student work, formal team or one-on-one conversations, informal conversations at workstations, etc. We have found these practices essential to the transformation of students to practicing engineers; without them, many students would not have made the transformation. Ultimately, the course is time intensive for both students and instructors, but the processes we employ provide experience in a real-world industrial design process as a means to complete the students' professional training and allows for mentoring which impacts and assesses students in a way that no other courses currently include. The details presented in this paper might easily be incorporated into other design courses as a means to enhance learning and the design experience.

Introduction

The culminating experience for most engineering curricula is a capstone design course. These courses are targeted toward preparing students for real-world, post-graduation experiences. They also help to fulfill the design requirements of ABET¹ and provide unique opportunities in course assessment and student mentoring. In the courses, students are assessed based on their ability to integrate knowledge and skills gained throughout their undergraduate curriculum to solve a complex, interdisciplinary design problem.

A recent national survey of capstone design courses² provided a snapshot of practices common in capstone design instruction. Findings from this survey indicated that the majority of programs: a) use departmental teams, b) run the capstone lecture course and design experience in parallel, c) use the capstone lecture course to address the 'soft skills set', and d) see course instructors as mentors to the capstone project teams, among other findings.

In general, the findings of the survey reflect practices used in the biomedical engineering capstone course at Purdue University. However, we have taken the capstone course one step further, addressing the visions of the Engineer of 2020. In *Educating the Engineer of 2020*³, the National Academy of Engineering indicated that the education of engineers could be enriched if the focus was more on a) teaching, b) identifying and understanding how students learn, and c) mentoring students. A significant amount of time went into developing (and now continually improving) the undergraduate education component of the biomedical engineering program at Purdue University; we have met some of the proposals included in the book: a unique curriculum was established and a comprehensive assessment strategy (embracing outcomes-

based assessment) has been put into practice and engineering design is integrated throughout the curriculum, beginning in the first year. The capstone course is the culmination for both assessment and design, where individual student needs are met through mentoring sessions.

In our approach, we have linked learning, assessment, and mentoring requirements in the course. The strategic linkage of assessment and mentoring efforts allows directed and specific feedback to the students. This practice serves to motivate students and engage them more fully in the learning process, as opposed to simply being achievement oriented (i.e., focused on right and wrong answers). Furthermore, this process promotes each student's self awareness of their strengths and weaknesses as it relates to both their technical and professional development.

This paper describes the mentoring strategies implemented in the capstone course in the Weldon School of Biomedical Engineering at Purdue University. The processes described herein, which deviate from traditional grade-based mentoring, represent one strategy to improve student success in design courses and are anticipated to be easily implemented in any design course. Furthermore, these processes may prove advantageous in producing engineers with attributes of the Engineer of 2020⁴, which include: strong analytical skills, practical ingenuity, creativity/innovation, communication skills, leadership skills, and professionalism.

Operation of BME Capstone Course

The capstone design course, BME 405: *BME Design Project*, is a one semester, four credit hour course facilitated by a team of faculty and professional staff members. It is impractical to expect one person (even two in our model) to have a knowledge base broad enough to guide the teams in every aspect of the design process. This is one reason our teaching staff is large, consisting of two faculty instructors, at least two additional support faculty, two laboratory coordinators, three research engineers, and at least three graduate student teaching assistants.

The structured learning components include one 50 minute lecture session and two 4 hour laboratory periods each week. In addition, lab space and resources are available to students throughout the week. The design project and supporting faculty/staff members are strategically selected each semester so to match faculty interest, expertise, industrial perspective, and research areas with design project attributes.

Although course design projects change each semester, every project incorporates several core components. These include: a) knowledge/information from at least two of the Weldon School's six research areas of excellence (Biomaterials and Tissues Engineering, Biomedical Imaging and Optics, Bionanotechnology and Biosensors, Neural Engineering, Orthopaedic Biomechanics and Implants, and Computational and Systems Biology), b) interface between living and nonliving materials and systems, and c) three or four distinct design subsystems. Each design problem involves the development of a medically useful product, though the application varies each semester (i.e., cardiovascular, neurological, orthopedic). The process of choosing a project involves students, faculty, and staff members. In one of the earlier professional development courses, students are asked to identify unmet clinical needs that could be solved by a biomedical engineer. These ideas provided by the students are collected and evaluated with others provided by faculty, clinicians, and industrial partners for potential use as a senior design project. From

this list, senior design faculty and professional staff select and develop two design problems to be used in the following year.

Students work in teams of 3-4 (corresponding with the number of distinct design elements in the project) to solve the design problem presented by a fictitious customer (composed of the faculty members instructing that semester). Student teams are assigned based on the following criteria: a) Myers-Briggs Type Indicator® (MBTI)^{5,6} preferences, b) previous experience and expertise (determined from a submitted resume), and c) academic ability (GPA-based). The overall goal of the team assignment strategy is to obtain teams that are balanced in terms of personality types, technical strengths and weaknesses, and diversity. Three times during the semester, students complete self- and peer-evaluations in which they reflect and comment on the effectiveness of their team.

The lecture portion of the course is structured to provide students with a relevant design context that includes both technical and real world constraints. Lectures cover several design and industry-related topics, as well as project-driven topics. These include project management and scheduling, engineering economics, design process documentation, the Food and Drug Administration (FDA) and regulatory processes, ethics, animal and clinical trials, patents and copyrights, and marketing. In addition to these broad topics, the curriculum also allows for several project-specific lectures. For instance, in Spring 2007 when the design project required students to develop a cardiopulmonary resuscitation (CPR) assist device, lecture time was allocated for physiology topics relevant to CPR, reflections by emergency medical personnel, CPR models, and the ethical issues related to CPR. These project-specific lectures provide design teams with an in-depth understanding of the clinical problem and realistic design constraints as they work to complete their design project.

Course assignments are geared towards modeling the industrial design process and underscore the importance of design documentation. As a first step, each student must brainstorm and propose solution(s) to the given problem, an exercise which also serves to prepare each person for their first team meeting. The first team assignment asks students to report on relevant literature and market analysis, providing them both motivation and a framework upon which to develop a consensus design strategy. The remaining assignments are related to project management and system design, building, and performance. The majority of the written assignments build upon one another as the semester progresses fostering continual evolution and improvement. Through out this iterative documentation process, students repeatedly receive direct and specific feedback from the course staff on their technical content as well as their communication strategies and are able to use this to modify and improve their future documentation, design processes, and ultimately the product itself.

Assessment in the Capstone Course

A study by McKenzie et al.⁷ reported on findings from a national survey regarding the role and nature of assessment in capstone courses. Data indicated that 80% of respondents felt that each outcome of criterion 3 could be assessed in capstone courses, though none of the criteria are assessed to the point that they could be. The authors suggest that this indicates the faculty members are not prepared to create assessment strategies and then manage the data. Two other

important findings in this report are that the focus of most courses is on project milestones and not educational learning objectives and that the majority of respondents use assessment data to provide feedback to faculty and to monitor student progress.

Our instruction and assessment strategy addresses each of these concerns. We believe that any design course instructor can develop useful and successful assessment strategies. However, it takes research, time, and a sincere interest in student success. The other two concerns are addressed together. Assessment is built into the curriculum of our biomedical engineering capstone course. On the first day of class, students and instructors discuss what will be assessed during the course. They review the course outcomes (Table 1), the BME performance criteria (the specific, measurable statements used to assess achievement of course outcomes), and the assessment strategies used in the course. The course outcomes and BME performance criteria are also included in the course manual and discussed throughout the semester to make students aware of their progress towards achieving the appropriate level of mastery of these skill sets. The BME program performance criteria were mapped to senior design project course assignments (paper assignments, oral presentations, demonstrations, etc.), and rubrics were generated which clearly demonstrate the expectations and assessments associated with each assignment are included in the course manual. These are discussed on the first day of class, and then reminders are given frequently throughout the semester. In general, the rubrics help students understand learning objectives and places achievement of both in their hands.

Table 1. BME Capstone Course Outcomes

Upon completion of the course, students are expected to demonstrate the ability to: 1) integrate and apply knowledge and skills obtained in earlier course work with new concepts and practices essential to the design and testing of a system or device to meet desired needs, 2) implement the engineering design process and project management within the context of relevant design constraints, 3) effectively communicate skills in oral and written form, both individually and as part of a team, and 4) explain/discuss realistic design constraints, including regulatory issues, societal influences, and ethical and professional responsibilities of biomedical engineers, as related to the engineering design process.

Student achievement of the performance criteria helps determine final course grades; a student may not complete the course if they do not pass the criteria. This strategy has proven successful (perhaps due to the fear of failing), as students are more aware of the learning objectives and assessment strategy than ever. Students are encouraged to use instructor feedback and repeat assignments as necessary to ensure their passing. Overall, a significant amount of direct assessment data, reflecting the students' abilities, is generated using the grade rubrics and indirect assessment data is acquired through an end of course survey. (Note, we do not rely solely on this data for assessment of the curriculum; data across the curriculum is collected based upon a strategic mapping of program outcomes/performance criteria to the courses.)

Our practices are further supported by a report from the National Research Council⁸, which indicated that students learn more when instruction and assessment are integrally related and that students learn more when they understand the criteria they are evaluated against. The practices listed above describe our efforts to directly link instruction and mentoring with assessment.

However, to simultaneously engage students in the assessment process and develop their design skills, we have found it essential to incorporate specific and strategic mentoring throughout the course.

Mentoring in the Capstone Course

In 1994, Chism⁹ identified four essential elements that students want from their professors and classes: 1) to feel welcome, 2) to be treated as individuals, 3) to feel they can fully participate, and 4) to be treated fairly. Our experiences suggest that mentoring is a key strategy to achieve each of these and to ultimately affect the transformation from student to effective engineer.

Mentoring has been a part of our capstone course since its conception. In the first course offering, mentoring was introduced to guide/move students along the design process, more as a tool to motivate them when the instructing staff observed that the students were behind in the schedule of milestones. However, it was observed that mentoring not only addressed this concern, but also made students more aware of their own technical knowledge strengths and weaknesses, contributions to the team effort, priorities, and time management skills.

The National Academy of Sciences book *Adviser, Teacher, Role Model, Friend*¹⁰ indicates that to listen patiently, nurture self-sufficiency, share yourself, and be constructive are important attributes of a successful mentor. In our model, the two lead course faculty members serve as the primary mentors, though professional staff members also contribute to this effort. While being knowledgeable of these attributes may be beneficial, ultimately each instructor must discover what works best for them through practice. Some instructors may have a natural ability to be an effective mentor, while others may benefit from guidance in this area.

In the Spring 2007 course, students were scheduled to interact with course instructors and receive detailed feedback on their design strategies a minimum of seven times (Table 2) over the semester; this number was typically much higher though as the students often sought out a faculty member or professional staff member to discuss their design strategy. The first meeting occurred during the second week, when the course instructors met with each team to answer questions regarding the design criteria and initial design proposals. The next team meeting was during the fourth week of classes, when each team met with the instructors to discuss the components they planned to use in their design. At this meeting, the instructors were able to pose questions that helped students evolve their potential design concepts and ensure they were converging to a proposed solution. Week five was the first formal review; each team wrote a paper describing and presented an oral presentation on their proposed design strategy to the instructional staff. The teams received immediate feedback during the twenty minute question and answer session, but also received detailed feedback on their papers. The feedback on the papers came in the form of a multi-page document containing critical and guiding questions to help students move forward in the design process. The first individual mentoring sessions occurred during the eighth and ninth week of classes. In week eight, each student submitted a paper describing the design strategy employed for their individual component and gave a demonstration of their parts/pieces. In week nine, with data from the student papers and demonstrations, the instructors discussed each individual's progress to date in the design process, answered technical questions, and presented each student with an initial assessment of their

performance as related to each of the BME performance criteria. At this point students and faculty discussed the areas in which the student was working well and where they needed to improve, a list of accomplishments for the following weeks was also created. In week eleven, the instructors focused their mentoring efforts on a smaller group of students who were struggling in terms of their professional development and/or struggling to achieve the course learning objectives. Working together, opportunities were identified for the students' to demonstrate progress and achievement of performance criteria in the remaining assignments and time. The second individual mentoring session occurred in the fourteenth week of the semester. In this session to wrap up and identify any potential hurdles to successfully completing the design project as well as continue to provide feedback on progress and encouragement.

The mentoring strategy we have employed allows the mentoring process to be tailored to each student, as each student's needs can be unique and varied over the semester. Students differ in terms of their personality preferences, learning styles, approaches to learning, and intellectual development¹¹. In a "real-world" engineering design setting like the capstone experience, many students may have a tendency to feel overwhelmed with the enormity and complexity of the task at hand. However, as also indicated by Vesilind¹², we have found that student-specific mentoring provides the most effective means to impact each student (regardless of their preferences) in a manner consistent with their individual needs. In both semesters of operation, there have been students who excelled at the hands-on design and build aspects of the course but struggled to complete an adequate level of design documentation. Likewise, there are students who excelled at completion of the design documentation and presentation, but lacked the ability to implement their concepts effectively. However, through mentoring we have been able to effectively help each type of student successfully move through the design process.

Our processes also support the findings of Taylor et al.¹³ and McKenna et al.¹⁴ Taylor et al.¹³ wrote that successful learning experiences in capstone courses come when faculty leave the traditional role of lecturer and take on the role of coach. This paper¹³ further indicated that the coach has three responsibilities: mentor (providing support), mediator (a buffer between external reviewers/sponsors and customers), and manager/facilitator (a guide for the team in team processes and the design process). Similarly, a survey of project mentors and students conducted in research by McKenna et al.¹⁴ identified three primary roles of a mentor. According to their results, both mentors and students felt that the mentor must 1) help set the pace of the project and keep tabs on student progress, 2) be able to refer students to specialists, vendors, etc., and 3) provide motivation and encouragement to the student teams.

Our definition of mentoring encompasses all three categories from the papers by both Taylor and McKenna. Our faculty and staff instructors provide detailed feedback and/or critical analysis questions to students on course assignments (managing), meet with students as individuals or in teams to discuss technical progress and/or options in the design process (motivating), support those struggling with an individual professional or technical skill or a team dynamics problem (mentoring).

Table 2. Mentoring Timeline in the BME Capstone Course

Week	Participants	Nature of Interaction	Purpose
2	Design Teams/Faculty	Informal discussion	Discuss design constraints and initial proposed solutions
4	Design Teams/ Faculty/Staff	Informal discussion	Discuss the components the teams wished to use in their design
5	Design Teams/ Faculty/Staff	Formal Preliminary Design Review	Critical evaluation of design approach
8	Design Teams/Faculty/Staff	Formal Individual Progress Assessment	Critical evaluation of individual design strategy and progress
9	Individual Students/Faculty	Informal discussion	Discuss individual responsibilities, progress to date, and achievement of BME performance criteria, and answer technical questions
11	Selected Intervention meetings	Informal discussion	For students needing more individual assistance or guidance.
12	Design Teams/Faculty/Staff	Formal Design Review	Critical evaluation of design strategy and progress to date
14	Individual Students/Faculty	Individual Demonstration Informal discussion	Discuss individual responsibilities, progress to date, achievement of BME performance criteria, and answer technical questions
15	Selected Intervention meetings Individual Students/Faculty/Staff	Informal discussion	Discuss achievement of BME performance criteria to date and determine strategies to meet the criteria

Outcomes

In Spring 2007, the end of course survey asked students specifically about the mentoring processes employed in class. Students were given a series of statements and asked to rank (1=not at all; 5=extremely well) how helpful mentoring was in achieving each. Data are included in Table 3 and indicated that the majority of students generally believed that the mentoring processes were effective to some extent. The low data point (a 2.65 in resolving team conflicts) could be due to the fact that there were no evident team problems throughout the course. Students had been working together in various teams for nearly four years at this point and reported that they were quite clear on how to work with each other despite the diversity created through team assignments in the course. Furthermore, the survey findings likely reflect the fact that the mentoring process was a new experience for each student. Based on our subjective observations, we have found that mentoring is critical in each issue described in Table 3. By more clearly identifying the goals of the mentoring process and continuing to evaluate and improve our techniques, we anticipate that student perception of the mentoring sessions will improve in years to come.

Table 3. Student Assessment of Mentoring Sessions

Topic	Average Rating (maximum possible = 5)
Understand the design problem and customer needs	3.56
Develop and complete your technical design	3.52
Resolve Team Conflicts	2.65
Understand your achievement of the BME performance criteria	3.1
Identify opportunities to improve your performance in the course and achieve the performance criteria	3.52
Professional Development	3.6

In addition to these questions, students were given the opportunity to provide their own thoughts on additional benefits of the mentoring sessions as well as suggest improvements for the sessions; these comments are summarized in Tables 4 and 5.

Table 4. Additional Benefits of the Mentoring Sessions

- Helped to keep self on track
- Helped to identify areas of improvement
- Helped to understand how I am perceived
- Great experience in professional development

Table 5. Suggested Improvements for the Mentoring Sessions

- More time needed per session, sessions often seemed rushed
- Meeting more often; bi-weekly meetings
- More one-on-one interaction
- Instructors shouldn't be so critical

The findings indicated in Table 4 are in line with expected outcomes of the mentoring sessions, and Table 5 suggests that students enjoyed the one-on-one instruction and interaction. The final point in Table 5 (relating to instructor criticism) likely reflects the fact that students had not received this type of direct feedback in any other course and felt uncomfortable with it at times. To address this, we already have plans to implement mentoring in the junior level laboratory courses (which are design-intensive). At this level, we will discuss the role of mentoring in the design process. We anticipate that this will make the transition easier in the capstone experience.

Conclusions and Future Work

In the end, mentoring must be effective for both the mentor and student. Students will ultimately feel some sense of satisfaction in completing course requirements, and with a rigorous mentoring strategy in place, the transformation from student to effective design engineer is much more likely to occur. We believe that through the mentoring process, the students have an increased motivation to learn, more engagement with the learning process, increased confidence in their problem-solving and other professional skills, and found a faculty member with whom they feel confident in approaching with other professional questions (e.g., recommendations, post-graduation plans, etc). In turn, mentoring faculty members find satisfaction through contributing in a significant way to the transformation that can occur as an outcome of a senior design

projects course. We have identified the initial concepts of a mentoring strategy that appears to be effective in our senior design course. Further evaluation and revision of these and other mentoring processes will be required to determine the most efficient and effective methods of mentoring senior design students. We believe that the opportunity for increased influence warrants these future studies.

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