Industry Engagement versus Faculty Mentorship in Engineering Senior Capstone Design Courses

Abstract:

The senior design capstone course is an important experience for engineering undergraduate students. This course prepares students for industry by having students solve open-ended real-world problems. During the course, a student team defines a problem, plans an approach, develops a solution, and validates their solution, which culminates in oral and written dissemination. Typically, undergraduate programs have provided students with faculty mentors to develop a solution for a specific project. In order for projects and teams to be successful, the mentors must provide invaluable support, collaboration, and interest in the success of the project. However, these mentors do not always identify appropriate projects that meet ABET guidelines, as this can be difficult without support from industry sponsors and other outside mentorship.

The purpose of this study is to examine whether industry sponsorship versus faculty mentorship based projects provide adequate support for senior capstone student teams. To this end, the following research questions are posed: 1) what are the differences between mentorship guidance, availability, and student success in senior capstone courses for projects that are led by industry sponsors versus faculty mentors? 2) How do the identification of projects in industry sponsored versus faculty mentored projects align with ABET guidelines?

In a highest-research level R1 university, 147 undergraduate seniors in biomedical engineering and materials science programs were placed in teams of 5-6 students and assigned to either industry sponsored or faculty mentored projects. Out of these projects, 19 teams were assigned to faculty mentored projects and 11 teams were assigned to industry sponsored projects. A student survey was provided to assess the level of meeting availability for guidance, equipment and fabrication support, as well as level of support provided by the mentors. In addition, a mentor survey was used to assess whether the industry and faculty sponsors utilized ABET guidelines that are typically assessed during a senior design course. It was found from the student surveys that both industry and faculty mentors provided adequate availability for guidance, and fabrication and support throughout the project. However, meeting availability and guidance of direction on their project was lower in students with industry mentors compared to faculty mentors. Furthermore, the instructional team of capstone courses should help further design industry mentored projects to include more open-ended problems and incorporate broader design constraints, as these ABET requirements were not as well met in industry mentored projects. Despite these shortcomings, the industry sponsored projects and mentors provided adequate guidance and preparation of sills for students, and should be incorporated in engineering capstone courses.

Introduction:

The senior design capstone course is an important experience for engineering undergraduate students. This course prepares students for industry by having students solve open-ended real-world problems[1]. In particular, the senior capstone course involves solving problems posed from industry and faculty rather than "made up" projects[2,3] to allow for real-world situations experienced post degree. These problems typically require simulations using controlled real-world situations designed to meet specific learning objectives, or prototyping in a real-world environment[2] in which students are exposed to real situations with open-ended projects. The design problems posed to the students allow for the practical side of engineering design to be taught in the engineering curriculum of a university, as it culminates the students' learning in a final hands-on project[2].

The traditional engineering capstone course provides students with these real-world problems by working with an advisor from the field through an apprenticeship[4]. These advisors can be industry representatives, entrepreneurs, physicians, faculty members, or other professionals in the field. This client-advisor mentorship provides students with the opportunity for situated learning in which they can apply their skills and knowledge towards a robust understanding of what is means to be an engineer[4]. Furthermore, it allows students to be able to become exposed to the professional community and understand how research, industry, and entrepreneurs solve problems or needs within their field of practice. However, it is unclear whether the industry and entrepreneurial professionals versus faculty mentors or other mentors in academia (e.g. physicians, technicians, or graduate students) provide adequate training and support for student teams to be able to contextualize a problem or need and learn how to develop and disseminate an innovative solution. The purpose of this study is to examine the level of support given to engineering capstone student teams from different mentor types: industry professional mentors versus academic faculty mentors.

Related Work:

During the capstone course, a student team defines a problem, plans an approach, develops a solution to the problem, and validates their solution, which is disseminated either or both through oral and/or written communication[4]. These activities are typically conducted over one or two semesters, although future work is required to understand which duration is most beneficial for learning outcomes and available resources[5]. Furthermore, the activities performed throughout the capstone course are designed to promote soft and hard skills that are rarely taught in the traditional engineering courses[6].

In order to promote the above soft skills throughout the capstone course, students are often required to work in teams on a real-world project. Previous research has found that the team size has a significant effect on learning performance[7]. For example, in a study conducted by Chou and Chang[7], it was found that smaller groups (≤ 4 students) led to higher satisfaction of knowledge acquisition, performances, and skill development. Furthermore, small group sizes have been found as more beneficial for promoting student learning in other studies[5], so most capstone team sizes across universities limit team sizes to ≤ 6 students[8]. By limiting the size of the teams, problems such as free-riding, social loafing, and conformity[5, 9, 10, 11] can be avoided during the student learning experience. However, smaller team sizes can lead to increased resource requirements to manage teams and provide sufficient expertise, guidance, and cost for prototyping and testing[5].

Due to ABET's emphasis on providing an open-ended course that culminates in using students' knowledge from their other courses[12], undergraduate engineering programs have focused on providing students with real-world open-ended engineering problems. Typically, senior design courses focus on the following ABET guidelines: 1) promote the development of student creativity, 2) use open-ended problems, 3) use design methodology, 4) incorporate the formulation of design statements and specifications, 4) provide opportunities to evaluate alternative solutions, 6) allow students to evaluate design feasibility, and 7) provide opportunities to consider economic factors, safety, reliability, aesthetics, ethics, and social impact. In addition, General Criterion 4 requires that a student participate in a major design experience[12]. In addition, in ABET's General Criterion 3, student outcome (2) requires that students demonstrate "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors"[12]. General Criterion 5 also states that "students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints"[12]. In particular, Table 1 describes ABET student outcomes that are promoted during the engineering senior capstone course. It can be noted from the table that most capstone courses attempt to meet all student outcomes associated with ABET Criterion 3 through open-ended projects and different forms of dissemination (e.g. presentations, reports, posters)[4].

Table 1: ABET student outcomes from Criteria 3 promoted during the engineering senior capstone course[13].

Student Outcome	**Description**
1	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2	An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3	An ability to communicate effectively with a range of audiences
4	An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5	An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Due to the above several requirements among ABET student outcomes, senior engineering capstone projects must be carefully selected such that there is an appropriate level of challenges that are feasible to complete by a team of undergraduate students within the constraints of the course and university resources available while promoting student engagement and motivation [14]. This can be challenging, however, as faculty, staff, and outside industries must provide effective promotion of student engagement as well as appropriate resources that are accessible to students. Accessible resources include adequate access, space, and training in prototyping equipment, testing equipment, and software[5].

Undergraduate programs have typically provided students with faculty mentors to develop a specific project related to their research or interests. In order for projects and teams to be successful, these mentors must provide invaluable support, physical and simulation resources, collaboration, and interest in the success of the project[15,16]. However, these mentors do not always identify appropriate projects that meet ABET guidelines[14], as this can be difficult without support from industry sponsors and other outside mentorship. As a result, this study examines the use of industry-sponsored mentors and projects and compares the differences in mentorship guidance and student success thus far in the course. The study also examines whether faculty versus industry-sponsored mentors and projects meet the required ABET criteria for senior engineering capstone courses[12].

Objective:

The purpose of this study is to examine whether the addition of industry sponsorship versus faculty mentorship based projects provide adequate support for senior capstone student teams. To this end, the following research questions are posed:

1) What are the differences between mentorship guidance, availability, and student success in senior capstone courses for projects that are led by industry sponsors versus faculty mentors?

2) How do the identification of projects in industry sponsored versus faculty mentored projects align with ABET guidelines?

Methods:

Senior Capstone Course Structure

In a highest-research level (R1) university, 147 undergraduate seniors in biomedical engineering and materials science programs underwent a 9-month senior capstone program[17] in which they were assigned either industry sponsored or faculty mentored projects. The course provided three-hour lectures per week to help students understand the necessary course learning outcomes associated with developing medical devices (Table 2). In particular, these course learning outcomes focused on both the soft and technical skills required for medical device development, including: 1) design strategies, techniques, tools, and protocols commonly encountered in biomedical engineering, 2) ethics, safety, failure models 3) economic analysis, new products and the patent process, and 4) Food and Drug Administration (FDA) product approval. In addition, students were provided with industry or faculty mentorship through meetings with their mentors throughout the course, as well as supplemental meetings with the instructional team. The instructional team consisted of three graduate student teaching assistants and three course instructors. The graduate student researchers had degrees in biomedical engineering, materials science, and chemical engineering. The course instructors also had varying degrees and fields of practice, including a full tenured biomedical engineering professor with a joint appointment in chemical and biomolecular engineering, an assistant professor of teaching in biomedical engineering, and a lecturer in materials science. The full professor is a serial entrepreneur, with over six companies, while the assistant teaching professor is an expert in engineering design and education, and the lecturer is a professional working in industry. These broad skills and expertise have allowed the professors to provide insights into entrepreneurship, academia, and industry, which highlight the various potential career opportunities the engineering students will engage in upon graduation.

Table 2: Course learning outcomes and corresponding ABET outcome mapping of the senior capstone program.

No.	**ABET Outcomes[13]**	**Course Learning Outcome**
1	5	Demonstrate leadership and teamwork skills in a project team environment.
2	6	List and define the various steps in bringing a biomedical product from concept to market.
3	5	Identify the realistic constraints of the team project.
4	5	Identify and assess challenges in each of the steps.
5	2	Articulate the impacts of the project in a global, economic, environmental and societal context.
6	6	Design and conduct experiments to verify team projects requirements.
7	1	Use knowledge in mathematics, statistics, biological sciences, physical sciences, and engineering to solve the problems at the interface of engineering and biology whenever required.
8	2	Use the appropriate computer tools to design, model, simulate, and/or operate, the team projects.
9	7	Apply engineering principles and practices to meet the challenges.
10	3	Demonstrate oral communication skills in presenting team projects.
11		Establish initial contacts with major local BME companies.
12	4	Demonstrate knowledge of contemporary issues related to biomedical engineering.

During fall quarter, students attended several lectures that introduced them to the design process, FDA approval process, and the commercialization process[17]. These lectures were supplemented with several homework assignments that allowed students to identify the unmet clinical need given their project, brainstorm potential solutions to their given real-world problem, and identify a design plan with consideration of FDA requirements and engineering standards. In addition, prior to forming teams in the beginning of the program, students attended lectures that focused on the science of team formation and cohesion. Through the use of team assessments (Target Training International Indigo Assessment[18]), students were able to identify internal behaviors, motivators, professional skills, and social emotional perceptions that align with other potential teammates. Once students were able to choose a team of 5-6 members that best fit their internal behaviors as well as external technical skills and fields of interests with guidance from the instructional team, they were able to use the team assessments and team science training to identify the team leader. This resulted in multidisciplinary teams that were assigned to either industry sponsored or faculty mentored projects based on team interest. Out of these projects, 19 student teams were assigned to faculty-mentored projects and 11 student teams were assigned to industry-sponsored projects.

Following a document of course roles and expectations, industry and faculty mentors were asked provide technical guidance, suggest milestones, and suggest additional skills and tools students would require to complete their project. In particular, they were asked to meet with the student team to provide weekly feedback given their schedule. Given their scientific, medical, and engineering expertise, they were also asked to discuss specialized skills and how they are performed, and demonstrate tools that students may not be aware of. In order to improve team cohesion and overall progress of the project, mentors were also asked to monitor student performance, relevance of work, progress, team and leadership skills, as well as communication among the team. Through monthly feedback reports, they provided communication feedback to the instructional team about the team's progress.

Once student teams and mentors were assigned, students focused on addressing clinical need, FDA and technical documentation, project planning and definition, and possible design solutions during the fall quarter. Once an initial design was chosen by the end of fall quarter, the students then focused on implementing the chosen design during the winter quarter. In class lectures, activities, and assignments focused on the design and redesign process, and preparatory skills required or spring quarter such as a business model, prototype verification and validation, and assessing potential failure modes. To provide support to the teams during the redesign process, the instructional team met with the student teams regularly to assess their performance and advice for project completion. This instructional team feedback assisted students with maintaining open communication across all stakeholders of the project, as well as technical and resource guidance.

The spring quarter of the program concentrated on finalization and validation of their working prototypes with consideration of FDA and engineering standards, as well as public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors (ABET Criteria 3, Table 1). Professional skills were also emphasized, as students were required to present, create poster, and elevator pitches in a variety of engineering and business venues. Specifically, students submitted business plans to various competitions (e.g. DEBUT business competition by VentureWell, University of California Irvine (UCI) Center for Innovation and Entrepreneurship New Venture Competition), undergraduate engineering conference (Undergraduate Research Opportunities Program Symposium), and a final awards symposium. The final awards symposium allowed students to present their working prototypes, final design posters, and disseminate their projects through a two-minute elevator pitch to an outside board of faculty, physicians, industry sponsors, inventors, and entrepreneurs who were not involved in the project. At the symposium, students competed for a fellowship to continue commercialization of their product as well as design awards for best engineering designs and prototypes.

By the end of the course, students disseminated their project and finding through a written final report, presentation to industry representatives, faculty, and a general audience, as well as a poster session that is disseminated to the school of engineering. For the final report, the student groups submit full engineering and business documentation the course learning outcomes described in Table 2 that are directly related to ABET's Criterion 3 student outcomes[13] (Table 1).

Mentor and Student Surveys

A student survey presented during the course was provided as part of an assignment to assess the level of meeting availability for guidance, equipment and fabrication support, as well as level of student support provided by the mentors as perceived by the student teams. In addition, a mentor survey was presented to assess whether the industry and faculty sponsors utilized the following ABET guidelines: 1) promote the development of student creativity, 2) use open-ended problems, 3) use design methodology, 4) incorporate the formulation of design statements and specifications, 4) provide opportunities to evaluate alternative solutions, 6) allow students to evaluate design feasibility, and 7) provide opportunities to consider economic factors, safety, reliability, aesthetics, ethics, and social impact[12]. All students and mentors that participated in the surveys were provided with informed consent (UCI IRB Approval Number: 2018-4211).

It is hypothesized that the faculty and industry mentors have difference in availability and desired outcomes regarding student success (research question 1 in the Objectives section above), and may not all consider ABET's guidelines when mentoring their student teams. For instance, it can be hypothesized that the industry sponsors may have had less availability to meet with teams to provide guidance due to their professional responsibilities, while faculty mentors may not have had as much access to available prototyping and equipment for validation of their student projects. To identify whether mentors are considering ABET's guidelines, the following questions were posed in the mentor survey:

1) Please rate your current project given the following ABET learning outcomes:
    a. Promotes the development of student creativity
    b. Uses open-ended problems
    c. Uses design methodology
    d. Incorporates the formulation of design statements and specifications
    e. Provides opportunities to evaluate alternative solutions
    f. Allows students to evaluate design feasibility
    g. Provides opportunities to consider economic factors, safety, reliability, aesthetics, ethics, and social impact
2) My team and I have considered the following throughout the design process:

a. Principles of engineering
b. Principles of science
c. Principles of mathematics
d. Public health design constraints
e. Safety and welfare design constraints
f. Global design constraints
g. Social and cultural design constraints
h. Environmental design constraints
i. Economic design constraints
j. Manufacturability design constraints
k. Ergonomics design constraints
l. Ethical design constraints
m. Appropriate experimentation
n. Appropriate engineering standards
o. Appropriate FDA standards.

To elucidate mentorship guidance, availability, and assistance with student success in the capstone course, the following questions were posed in the student survey:

1) My mentor is a: faculty mentor or industry representative.
2) How frequency does your mentor meet with the team (weekly, bi-weekly, monthly, or infrequently)?
3) How well does your mentor provide adequate guidance on the direction of the project?
4) Is your mentor regularly available for guidance?
5) Does your mentor provide adequate equipment and fabrication support?
6) What positive, negative, or other comments do you have regarding your mentor and their guidance throughout the program thus far?

Qualitative and Quantitative Analyses

Both qualitative and quantitative analyses was performed to assess the above research questions, and elucidate the challenges and advantages of industry sponsored versus faculty sponsored support of student teams. The quantitative statistical analyses were performed on the student survey to identify differences in survey responses for those with industry representative mentors and faculty mentors. Analyses were performed using the open source programming environment R and the stats package[19], as well as the MatLab statistical processing toolbox (MathWorks, Natick, MA). Questions three through five of the student survey also utilized a 5-point Likert scale of strongly disagree, disagree, neither agree nor disagree, agree, or strongly agree to be able to perform quantitative analyses given their mentor type. Given the Likert of the student and mentor surveys, quantitative analysis of the surveys utilized a Wilcoxon rank sum test, as the distribution of responses had a Poisson distribution and thus cannot assume sample independence (see Figure 1 below in the Results section). The Wilcoxon rank sum test is a non-parametric method of the paired Student's t-test[20]. For the categorical responses, an independent samples t-test was utilized to compare student and mentor responses across faculty and industry mentors.

For the mentor survey, question 2 used a 5-point Likert scale of never, little, somewhat, much, and a great deal, while question 3 utilized a categorical response of yes or no. These responses were compared across faculty and industry mentor responses using the Wilcoxon rank sum test, as described above. Finally, qualitative analyses was performed using question 5 of the student survey where students were asked to provide additional positive and negative comments regarding their mentor's guidance thus far in the senior capstone program.

<u>Results:</u>

Student Survey Results

It was found that 61.4% of the 145 students who took the class completed the student survey (N = 89). The demographic data of the course is presented in Table 3 below, as students who responded to the survey were not required to submit demographic information to maintain confidentiality and openness of their responses. It can be noted that the majority of students were either biomedical engineering or materials science engineering majors, as the senior design course was required for these majors. Of the survey respondents, 36 students had industry representatives as their mentors and 53 students had faculty mentors.

Table 3: Demographics of the study participants who complete the student online survey.

Number of Students: 145			
Low Income	26%		
First Generation	34%		
International	13%		
Transfer	26%		
Major	Biomedical Engineering	Materials Science Engineering	Other
	73%	24%	2.8%

Prior to performing quantitative analyses, the student survey response distribution was analyzed to determine the appropriate statistical analysis method. As seen in Figure 1 below, the student survey responses had a Poisson distribution type; thus, the non-parametric Wilcoxon rank sum test was performed. This is due to the majority of students found that their mentors provided adequate meeting availability, guidance on direction, were regularly available for guidance, and provided adequate fabrication and support regardless of their mentor type.

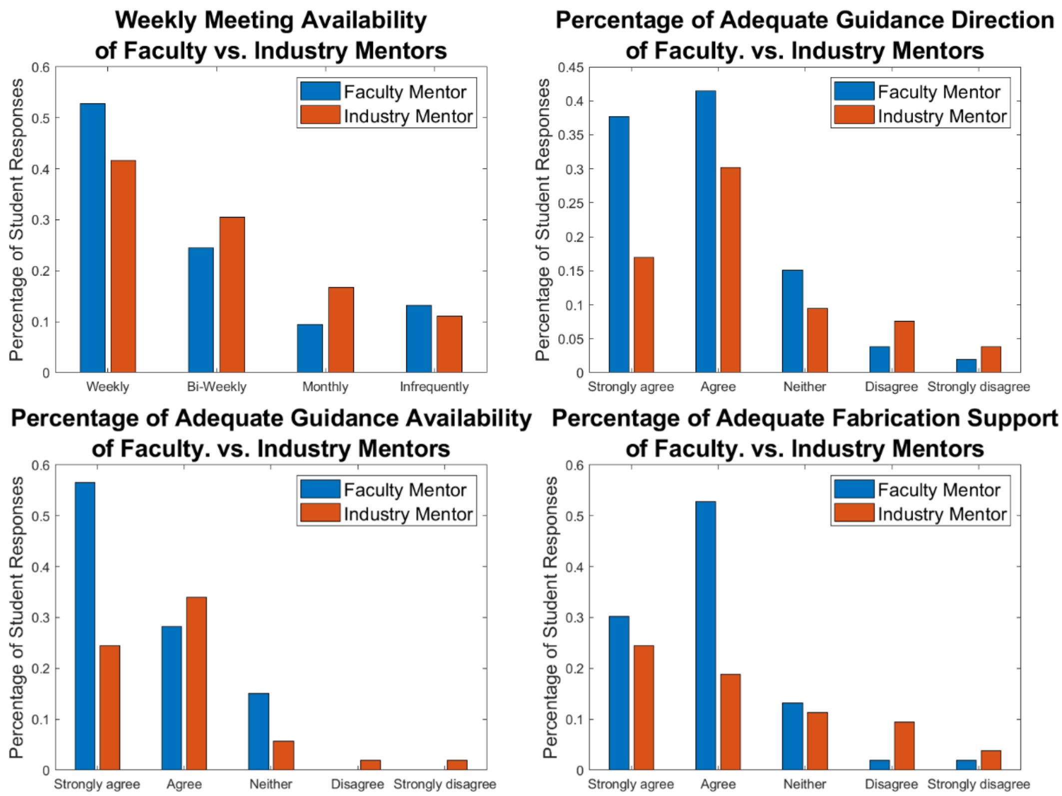

Figure 1: Distribution of the student survey responses: a) frequency of mentor meetings, b) adequacy of providing guidance on the direction of the project, c) availability for guidance, d) adequacy of equipment and fabrication support.

Using the Wilcoxon rank sum test, it was found that there was no significant different between student responses based on their mentor type (significance level: 0.05). This is expected, as the majority of students found that both types of mentors provided adequate meeting time, guidance on direction and availability for guidance, as well as fabrication and equipment support. However, as seen in Figure 1 above, it can be noted that based on the percentages student responses (normalized by the number of student responses per mentor type), more students found that faculty mentors met with their student team more regularly than those students who had industry mentors. In addition, a higher percentage of students who had faculty mentors as their sponsors believed that their mentors provided adequate guidance on the direction of the project and were more available for guidance. Conversely, those groups who had an industry representative as their mentor, a higher percentage of believed that their mentor did not provide an adequate level of availability or direction for guidance on their capstone project. Finally, student groups with faculty mentors also felt that they had a stronger level of support in regards of equipment and fabrication resources than those groups who had an industry mentor (Figure 1).

After qualitatively assessing the student survey results, the majority of comments from the student responses were positive regardless of the mentor type. For instance, positive comments from those with industry mentors are included in Table 4 below. The positive comments from those with faculty mentors also highlights the adequate level of guidance for student teams (Table 4). In addition, many positive comments were made regarding the availability for consistent meetings for feedback and additional resources. However, some students mentioned that although that their industry mentor provided adequate guidance, they had limited availability for feedback or provided unclear milestones (Table 4).

Table 4: Positive and negative comments from the student survey results of the industry and .

Industry Mentor Positive Comments:
XXXX has been an invaluable resource and mentor helping guide young engineers to the correct ways to develop medical devices based on extensive research-based clinical needs. He asks hard questions, not to belittle us, but to empower us to better understand and question the status quo. You cannot pay for the quality one on one time we have received and are extremely grateful for the opportunity to work with him.
XXXX provide guidance regarding the project as well as their experience in the professional engineering world. Both are invaluable to our team's growth as engineers.
Faculty Mentor Positive Comments:
Our engineering mentor is great at communicating with the team and making suggestions to fixing problems we run into. She also provides us with additional sources that could be helpful in the prototyping process.
XXX has been guiding us perfectly so far. She has helped us both communicate and organize effectively. Our mentor meetings are scheduled for once a week and are quite constructive/
Industry Mentor Negative Comments:
The only issue is we have not had regular meetings with them and thus there is a large gap in communication between our team and the mentors.
XXXX is very well-versed in the neurovascular space, and provides us with excellent feedback on our design conceptions. However, I feel that we were not given clear direction on the scope and ask of the project.

Mentor Survey Results

For the mentor surveys, 64.3% of the 28 mentors completed the mentor survey (N = 9 industry mentors, and N = 9 faculty mentors). Similar to the distributions of the responses to the Likert questions in the student surveys, the mentor survey responses also had a Poisson distribution, as the majority of mentors believed that their project met most of the ABET learning outcomes “a great deal” (see the Qualitative and Quantitative Analyses in the Methods section above). After performing the Wilcoxon rank sum test, it was found that there was no statistical differences between mentor responses and their consideration of ABET learning outcomes throughout the capstone course. However, as seen in Figure 2 below, it can be noted that one faculty mentor reported that their project did not use open-ended problems. Furthermore, four industry mentors reported that their project either did not use open-ended problems, incorporate the formulation of design statements and specifications, provide opportunities to evaluate alternative solutions, or provide opportunities to consider economic factors, safety, reliability, aesthetics, ethics, and social impact. Although not statistically significant when compared to the responses by faculty mentors, it is concerning as these learning outcomes of are particular importance for engineering capstone course projects.

In addition to analyzing the level of ABET learning outcomes across mentors (Figure 2), the considerations of engineering, math, and science principles, various design constraints, appropriate experimentation, and appropriate standards were also analyzed using categorical responses (Figure 3). It was found that even though there was no statistical significant difference across faculty and mentor responses ($p < 0.05$), more industry mentors (> 3 mentor responses) reported that they did not consider: 1) global design constraints, 2) social and cultural design constraints, 3) environmental design constraints, and 4) ethical design constraints. These constraints are not always considered in a medical device design, particularly depending on the specific application of the device or problem. Conversely, although industry mentors reported that they did not consider these constraints in their project, the majority of faculty mentors did consider them, as only three faculty mentors stated that they did not consider global design constraints, social and cultural design constraints, and ergonomics design constraints.

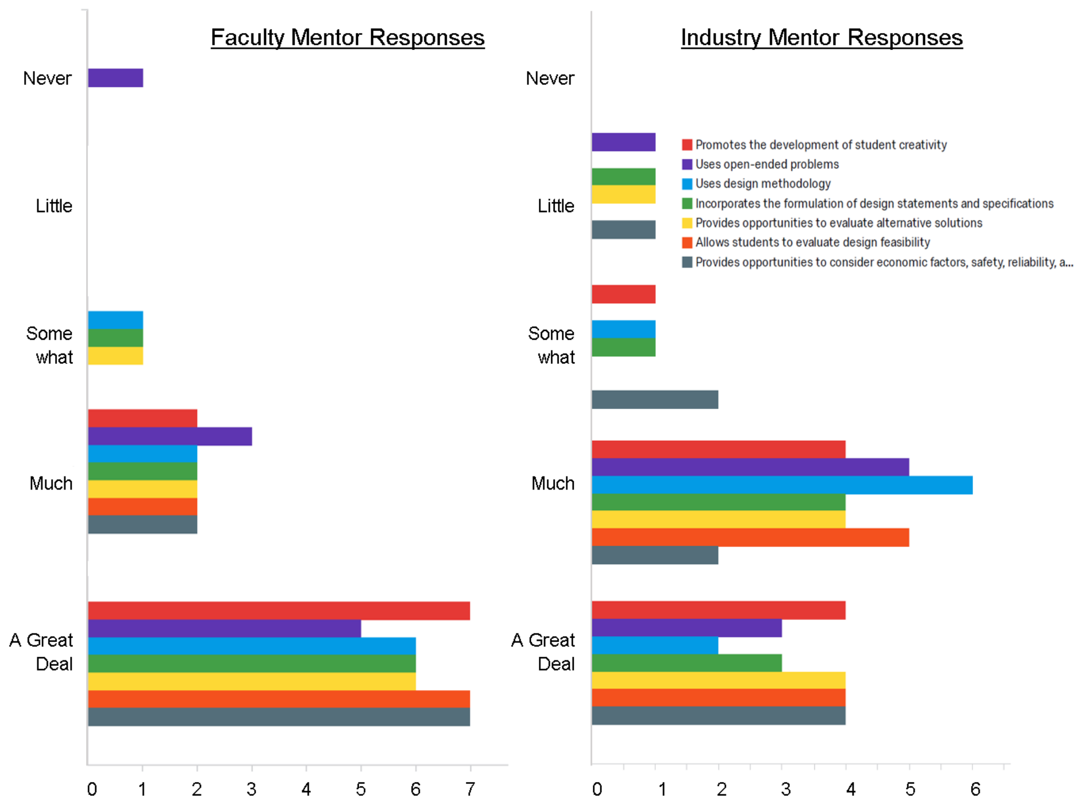

Figure 2: Comparison of faculty and industry mentor responses to rating their project to current ABET learning outcomes.

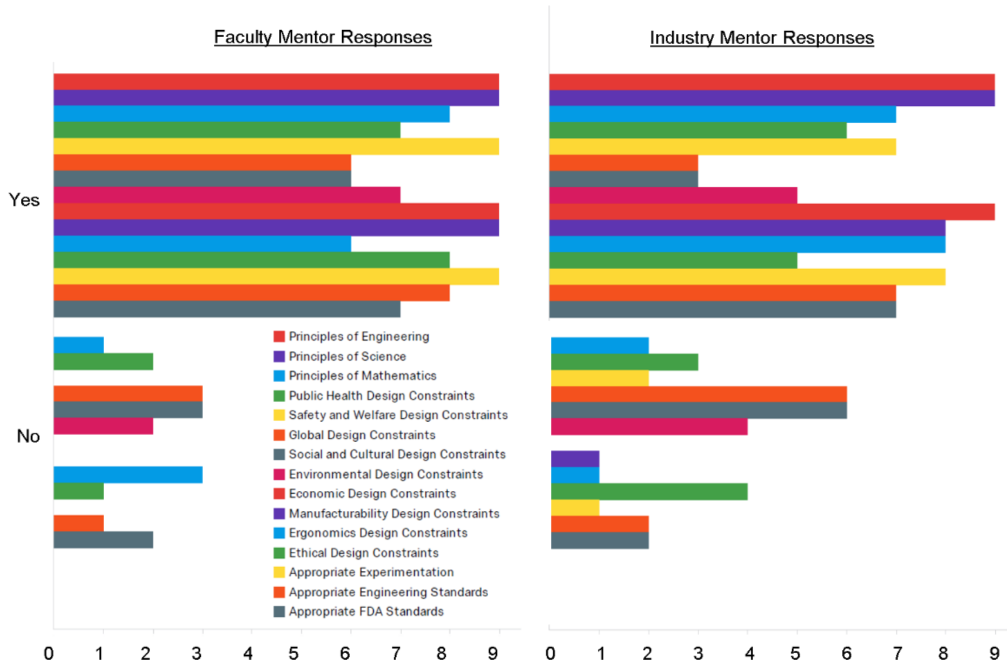

Figure 3: Comparison of mentor responses to consider various principles, design constraints, ethics, experimentation, and standards.

Discussion:

It can be seen from the student survey results that both faculty and industry mentors provided adequate levels of support in terms of meeting availability, guidance on direction, availability for guidance, and adequate fabrication and support (Figure 1). This suggests that industry mentors are adequate mentors in providing direction and guidance on a project despite their ongoing company responsibilities. However, a higher percentage of students with industry mentors believed that they did not receive adequate meeting availability and specific guidance on their project throughout the course. This may be due to their physical location and outside work requirements, resulting in less frequent meetings and a lower level of guidance. Despite these findings, these positive results suggest that industry mentors can provide similar levels of support, resources, and collaborations that can lead to successful projects. The "success" of the project was defined as using the appropriate engineering steps to develop and validate a physical prototype with proper written and oral dissemination, as described by the course learning outcomes in Table 2.

Concerning meeting appropriate ABET guidelines[12], it was found from the mentor survey results that faculty mentors utilized more open-ended problems to define their project than industry mentors (Figure 2). This is an important finding, as it suggests that industry mentors should be advised to incorporate more open-ended problems in their project definitions for students to be able to understand how to use engineering design and knowledge to solve problems that may not have a "correct" solution. This is a critical aspect of their senior capstone course, as ABET's emphasizes an open-ended course that culminates in using students' knowledge from their other courses[8]. Furthermore, it was found that several industry mentors did not consider incorporation of design statements and specifications, provide opportunities to consider other factors of design constraints beyond engineering design constraints (e.g. economic factors, safety, reliability, aesthetics, ethics, or social impact), or opportunities to evaluate alternative solutions (Figure 3). These ABET learning outcomes are important as students enter the workforce, as they are not typically learned during other coursework. It is recommended that industry mentored projects should be designed to allow for more open-ended problems that incorporate design constraints beyond engineering constraints. Projects that incorporate a wide variety of constraints using broader applications will allow students to explore alternative solutions that meet a wider market potential.

Conclusion:

It was found from the student surveys and performances of the student projects that both industry and faculty mentors provided adequate availability for guidance, and fabrication and support throughout the project. However, meeting availability and guidance of direction on their project was lower in students with industry mentors compared to faculty mentors, suggesting that the instructional team should more regularly encourage consistent meetings and clear direction during the project. Furthermore, the instructional team of capstone courses should help further design industry mentored projects to include more open-ended problems and incorporate broader design constraints, as these ABET requirements were not as well met in industry mentored project compared to faculty mentored projects. Despite these findings, the industry sponsored projects and mentors provided adequate guidance and preparation of sills for engineering students in the capstone course.

Acknowledgements:

We would like to thank the Division of Teaching Excellence and Innovation assisting with IRB approval, and Dr. Kameryn Denaro at the Teaching and Learning Research Center at UCI for her assistance with data collection. We would also like to thank the Department of Biomedical Engineering for their ongoing support. We would like to thank the Economic Development Agency (EDA) of the US Department of Commerce (ED15HDQ0200008), and the UCI Innovation and Entrepreneurship Legislative Initiative (AB2664).

References:

[1] C.L. Dym, A.M. Agogino, O. Eris, D.D. Frey, and L.J. Leifer. "Engineering design thinking, teaching, and learning." *IEEE Engineering Management Review,* vol. 34(1), pp. 65-92, 2006.

[2] A.J. Dutson, R.H. Todd, S.P. Magleby, and C.D. Sorensen. "A review of literature on teaching engineering design through project-oriented capstone courses." *Journal of Engineering Education*, vol. 86(1), pp. 17-28, 1997.

[3] A. Bright. "Teaching and learning in the engineering clinic program at Harvey Mudd College." *Journal of Engineering Education*, vol. 83(1), pp. 113-116, 1994.

[4] N. Hotaling, B.B. Fasse, L.F. Bost, C.D. Hermann, and C.R. Forest. "A quantitative analysis of the effects of a multidisciplinary engineering capstone design course." *Journal of Engineering Education*, vol.101(4), pp. 630-656, 2012.

[5] P.M. Griffin, S.O. Griffin, and D.C. Llewellyn. "The impact of group size and project duration on capstone design." *Journal of Engineering Education*, vol. 93(3), pp. 185-193, 2004.

[6] R.T. Prinsley, and K. Baranyai. *STEM skills in the workforce: what do employers want?* Office of the Chief Scientist, 2013 [eBook] Available: ResearchGate e-book.

[7] P.N. Chou, and C.C. Chang. "Small or Large? The Effect of Group Size on Engineering Students' Learning Satisfaction in Project Design Courses." *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 14(10), pp. 1579, 2018.

[8] R.H. Todd, S.P. Magleby, C.D. Sorensen, B.R. Swan, and D.K. Anthony. "A survey of capstone engineering courses in North America." *Journal of Engineering Education*, vol. 84(2), pp. 165-174, 1995.

[9] B. Latané, K. Williams, and S. Harkins. "Many hands make light the work: The causes and consequences of social loafing." *Journal of personality and social psychology*, vol. 37(6), pp. 822, 1979.

[10] P. Milgrom, and J. Roberts. *Economics, Organization and Management Inc.* Prentice-Hall, Englewood Cliffs, NJ, 1992.

[11] J.T. Strong, and R.E. Anderson. "Free-riding in group projects: Control mechanisms and preliminary data." *Journal of marketing education*, vol. 12(2), pp. 61-67, 1990.

[12] "Criteria for Accrediting Engineering Programs." ABET Engineering Accreditation Commission, Baltimore, MD, 2018.

[13] "General Criterion 3: Student Outcomes." ABET Engineering Accreditation Commission, Baltimore, MD, 2018.

[14] J.R. Katzenbach, and D.K. Smith. *The wisdom of teams: Creating the high-performance organization*. Harvard Business Review Press, Brighton, MA, 2015.

[15] Z. Zhou. "Managing engineering capstone design teams: A review of critical issues and success factors." In *IIE Annual Conference. Proceedings*, p. 3006. Institute of Industrial and Systems Engineers (IISE), 2014.

[16] D.G. Taylor, S.P. Magleby, R.H. Todd, and A.R. Parkinson. "Training faculty to coach capstone design teams." *International Journal of Engineering Education*, vol. 17(4/5), pp. 353-358, 2001.

[17] C.E. King, C.M. Hoo, W.C. Tang, and M. Khine. "Introducing entrepreneurship into a biomedical engineering capstone course at the University of California, Irvine." *Technology & Innovation*, vol. 20(3), pp. 179-195, 2019.

[18] D. Pistrui, J.K. Layer, and S. Dietrich. "Mapping the behaviors, motives and professional competencies of entrepreneurially minded engineers in theory and practice: an empirical investigation." In *Proc. of the 2012 American Society for Engineering Education Annual Conference*, San Antonio, TX, Jun 10-13, 2012.

[19] R Core Team. "R: A language and environment for statistical computing; 2015." pp. 0-4, 2018.

[20] F. Wilcoxon, S.K. Katti, R.A. Wilcox. "Critical values and probability levels for the Wilcoxon rank sum test and the Wilcoxon signed rank test." *Selected tables in mathematical statistics*, pp. 171-259, 1970.